EVALUATION OF TERRAIN COMPLEXITY BY AUTOCORRELATION

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FINAL REPORT TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PRINCIPAL INVESTIGATOR

RICHARD G. CRAIG
DEPARTMENT OF GEOLOGY
KENT STATE UNIVERSITY
KENT, OHIO 44242

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BY

AUTOCORRELATION

Final Report to the

National Aeronautics and Space Administration

Contract NAG 5-165

Principal Investigator

Richard G. Craig
Department of Geology
Kent State University
Kent, Ohio 44242

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I. INTRODUCTION

This research has grown out of previous work (Craig, 1982a) in which it was shown that landforms have a characteristic scale which can be determined by analysis of the degree of relation between adjacent slopes. Later (Craig 1982b) it was shown that the existence of this relation between adjacent slopes could be understood in light of certain "classical" theories of slope process and form which had been expressed as differential equations. Moreover, it now appears possible to infer process rates from observed forms in a fairly objective and precise manner.

Such work relates to remote sensing problems of interest to NASA because it has previously been shown that the above mentioned 'scale' of the landform impacts reflectance from that landform so as to yield a characteristic scale and dependence between adjacent pixels (picture elements) of LANDSAT data (Craig, 1979, 1981; Craig and Labovitz, 1980).

An even more intimate relation exists between the geobotanical studies of Dr. Mark Labovitz of NASA's Goddard Space Flight Center and the geomorphic theories outlined above. In these studies it is desired to find ways to recognize the surface expression of significant ore bodies using remotely sensed data. Emphasis is now being placed on the eastern United States. Here the ore body is likely to be obscured by regolith and vegetation. Thus one important aspect of the study must be to understand to what extent processes at work on the regolith are likely to influence the rate and mode of movement of materials from the ore body.

This study addresses five principal objectives related to the foregoing points. The first objective is to study and to characterize the topographic complexity of each of eight physiographic provinces in the

eastern half of the United States. This study is limited to eight provinces because of its exploratory nature. These particular provinces (see Figure 1) were chosen because they are of greatest interest at present in the ongoing geobotanical investigations. They are listed in Table I and the boundaries follow those of Fenneman (1938). Topographic complexity is here defined as the degree of relation between contiguous slope segments in a traverse as measured by the autocorrelation (Box and Jenkins, 1970). An important aspect of this part of the work is to determine an appropriate sampling scheme for each site. This is discussed in the section on methods (page 33).

Once the topographic complexity has been characterized at each site the second step is to compare the variability of autocorrelation within a small area (here defined as a single 7½' quadrangle) to the variability at widely separated and diverse areas within the same physiographic region. The objective of this step is to obtain some measure of the degree of uniformity of the autocorrelation (and hence presumably of the processes) which can be expected to be encountered within a given physiographic province. Since each province is supposed to represent a homogeneous structural, lithologic, climatic and geomorphic system it is reasonable to expect that the measures obtained for topographic complexity will be uniform within each province. If this can be shown to be so it will simplify the design of the geobotanical studies.

Whereas uniformity within provinces might be expected it is quite likely that provinces will differ in the extent to which each process is active both in an absolute and a relative sense (for a discussion of the processes being detected see Chapter II, "Fundamental Theory"). For example, we can expect slope wash to be more important in a province with a climate typified by intense rain showers and with a thin vegetative

Figure 1. Physiographic provinces and sections of the Eastern United States. Names are given in Table I. Large bold letters indicate sample sites used in this study.

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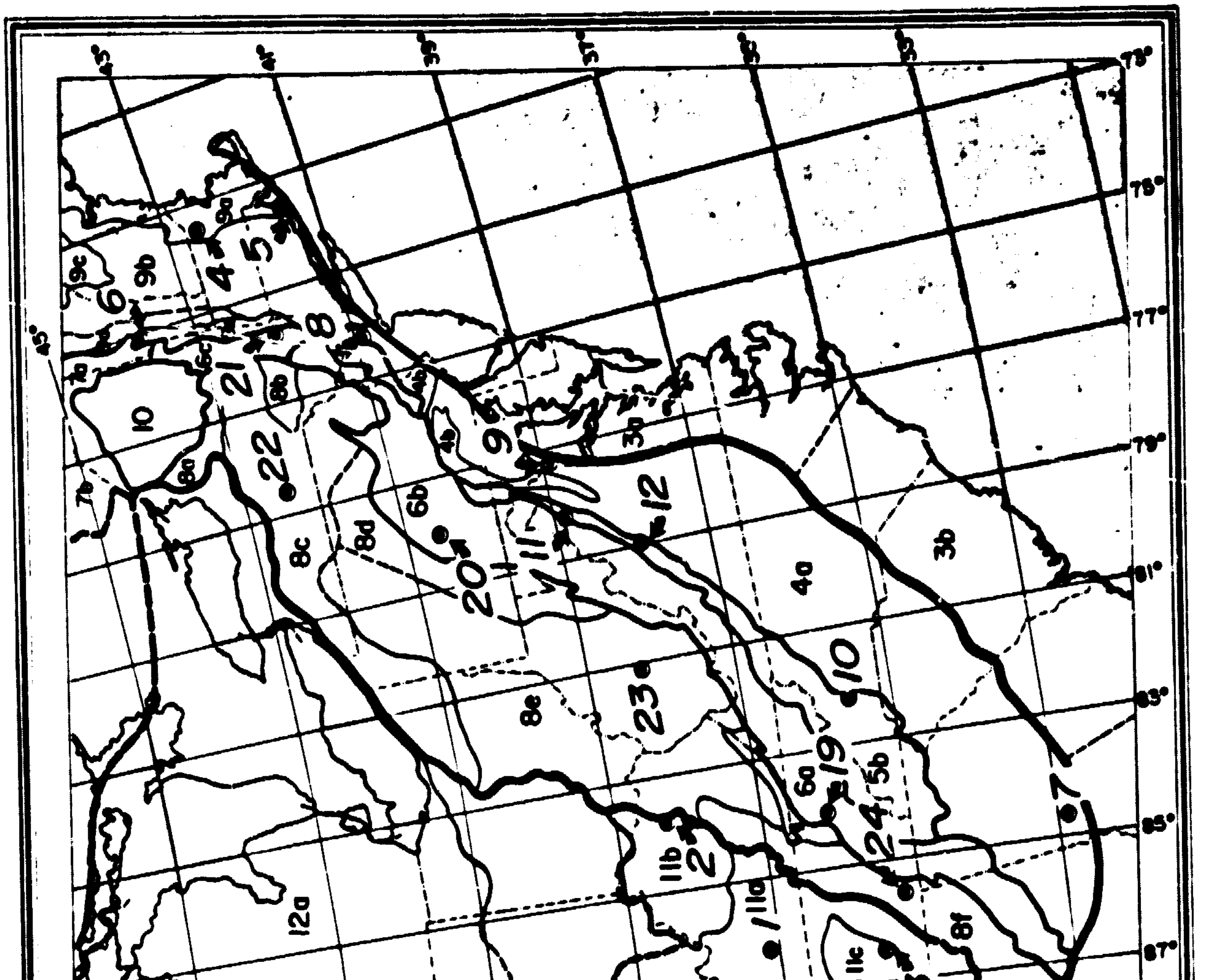

Table I. Physiographic provinces actually studied.

1. Interior Low Plateaus
2. New England province
3. Piedmont province
4. Blue Ridge province
5. Ozark Plateaus
6. Valley and Ridge
7. Appalachian Plateaus
8. Ouachita province

cover. On the other hand, creep might be more prevalent where the regolith is thick and temperature extremes more severe. Thus, the third major objective of this study is to compare and contrast the variability of autocorrelation across the eight physiographic regions. The results of this investigation should provide a guide to the extent of effort required in the geobotanical studies in each province.

Even if it is demonstrated that each physiographic region is homogeneous in topographic complexity within its boundaries and that there are significant differences between regions that does not imply that each province is distinct from every other one. It is not unlikely that we could find that provinces X and Y are similar to one another but distinct from provinces Z and W (which also define a group). Thus, a fourth major goal is to partition the total study area into subareas homogeneous in terrain complexity (autocorrelation properties). This study will also allow for the possibility that region A of province X may be more like region C of province Y than it is like region B of province X. Once these homogeneous subareas have been defined (if any exist at all) it will be easier to specify which geobotanical sampling procedure is appropriate in a given area.

The last point implies that there _are_ distinct strategies appropriate for areas depending upon the "terrain complexity" of that area. Thus, an appropriate question is to what extent should the differences in terrain complexity be translated into different geobotanical sampling techniques. Therefore, the fifth and final goal of this research is to show the relation between the complexity measured, the geomorphic process mix implied and the way in which geobotanical information will be modified into a new and more or less recognizable entity.

A discussion of the underlying theoretical framework of this study in the next section will be followed by a statement of the sampling method employed. Results are given next and are shown to be remarkably consistent with general expectations and particularly helpful in understanding geomorphic processes. This is followed by "Interpretation" both geomorphic and geobotanical. A section summarizing the major conclusions of this study (Chapter VI), is followed by some recommendations for future work (Chapter VII).

II. FUNDAMENTAL THEORY

The slope forming processes of interest are those which are dominantly transport limited (Carson and Kirkby, 1972) since these are most expected in regions typified by significant colluvial mantles as is common in much of the eastern U.S. Such processes are here divided into two groups and called, for brevity, slope wash and creep. These terms are shorthand for process groups which include solution on the one hand and solifluction on the other.

Such groups are distinguished by the underlying controls upon their rate of activity. Both are driven by gravity but the surface wash group is assumed to act at a rate proportional to the angle of slope. Steeper slopes will tend to display greater activity. On the other hand rates of creep will be influenced by the rate of curvature of the slope. It will be most active where the difference in slope angles between adjacent slope facets is the greatest.

These ideas can be made more intuitive when the characteristics of the processes are considered. Slope wash processes take material from the slope in a direct way. Once the material has been included in the transporting agent (usually water) it usually remains there until that agent has debouched from the slope. Thus, it is sufficient to set the transporting agent in motion. On the other hand creep acts in an incremental and cumulative fashion. Removal of material from one slope facet does not embed it in an agent that will totally remove it from the slope. Rather that material moves directly to the adjacent slope facet, which is now burdened with this additional load to be removed plus any regolith to be removed at that spot. Thus, the cumulative nature of creep processes

is such that creep can only be active on the whole slope when the slope angles are continuously increasing. The slope profile must be convex outward.

These theoretical notions have been stated more succinctly as a set of differential equations (Culling, 1965). These equations relate the rate of change of elevation at each point of the slope to the relevant slope parameter through a constant of proportionality. For slope wash the form is:

$$\frac{\partial y}{\partial t} = b \cdot \frac{\partial y}{\partial x} \tag{1}$$

and for creep it is:

$$\frac{\partial y}{\partial t} = a \cdot \frac{\partial^2 y}{\partial x^2} \tag{2}$$

In both of these equations x is taken to be the distance from the drainage divide of the slope, y is elevation and t is time. As can be seen these equations represent the development of a two-dimensional slope profile. They also are exact in that they fail to consider the possible influence of some other agent upon the slope profile. Such an influence could be most easily allowed by the addition of a random term to the original equation.

Another drawback to the existing equations is the lack of an objective means of estimating the values of the coefficients a and b. Typically if they are desired the equations must be solved for a variety of values and the correct value chosen by visual comparison to the slope of interest. Although not stated explicitly it appears to be reasonable to expect both values to be positive and less than one.

The separate equations have been combined into a single equation

(Hirano, 1975) which, under what appear to be reasonable assumptions, can be simplified to:

$$\frac{\partial y}{\partial t} = b\frac{\partial y}{\partial x} + a\frac{\partial^2 y}{\partial x^2} \tag{3}$$

The terms carry the same meaning as previously. This equation predicts the combined effect upon the slope profile of the two distinct processes. Again there is no formal means to include the effects of other agents, and there is no objective method of estimating a or b. However, these equations, most importantly the last one, can be converted to a discrete form and by making use of the ergodic hypothesis (substitution of space for time) can be related to existing profiles at specific locations. Moreover, these discrete forms have the advantage that they are members of a family of discrete equations which has been intensely studied in recent years (Box and Jenkins, 1970) and for which extremely sophisticated and comprehensive statistical tests are available.

The discrete form is achieved in this manner. Take

$$\frac{\partial y}{\partial t} = b\frac{\partial y}{\partial x} + a\frac{\partial^2 y}{\partial x^2} \tag{4}$$

which is equivalent to:

$$E^1(t) = b\,E^1(x-1) + a\,E^2(x-1) \tag{5}$$

and, under the ergodic hypothesis

$$E^1(t) = E^1(x) \tag{6}$$

so that

$$E^1(x) = b\,E^1(x-1) + a\,E^2(x-1) \tag{7}$$

which is equivalent to

$$\begin{aligned} & a\{[E(x-1) - E(x-2)] - [E(x-2) - E(x-3)]\} + b[E(x-1) - E(x-2)] \\ &= (b+a)[E(x-1) - E(x-2)] - a[E(x-2) - E(x-3)] \\ &= (b+a)\,E^1(x-1) - a\,E^1(x-2) \end{aligned} \tag{8}$$

and if we let

$$\begin{aligned} \phi_1 &= a + b \\ \phi_2 &= -a \end{aligned} \tag{9}$$

and add a term A(X) representing random effects introduced at point X independent of the agents being modelled we obtain an equation which is a member of the family of AutoRegressive-Integrated-Moving Average or ARIMA models.

$$\begin{aligned} E^d(x) = {} & \phi_1 E^d(x-1) + \phi_2 E^d(x-2) + \ldots + \phi_p E^d(x-p) + \\ & A(X) - \Theta_1 A(x-1) - \Theta_2 A(x-2) - \ldots - \Theta_q A(x-q) \end{aligned} \tag{10}$$

where

$$E^d(x) = E^{d-1}(x-1) - E^{d-1}(x-2) \tag{11}$$

The values of the parameters p, d and q define the order of the model. For the slopes the model is an ARIMA (2,1,0).

There are a number of considerations of importance in the study of landforms using the Box and Jenkins (1970) methodology. Generally, the

study is divided into three steps. The first is the identification of the appropriate model, that is the correct values of p, d and q for the series. It is suggested here that

$$p = 2$$
$$d = 1 \qquad (12)$$
$$q = 0$$

will be appropriate for almost any traverse of elevations observed in the eastern U.S. However, this assumption can be checked by using available identification procedures.

Once the order of the model has been chosen the next step is to estimate the values of the component coefficients, in this case ϕ_1 and ϕ_2. Following this step comes diagnostic checking. In this stage a number of specific tests are available to determine if the model chosen adequately fits the empirical data. Each of these steps has been followed for the traverses measured in this study. Before these are reported a number of elements of these steps should be presented.

Identification of the relevant model (i.e. the order of p, d and q) is most adequately done through the use of two items called the autocorrelation function and the partial autocorrelation function. Autocorrelation is the degree of relation between a sequence and itself at neighboring points at some fixed distance, k. Computing this correlation at successive values of k yields, a set of autocorrelations which can be plotted versus k to yield the autocorrelation function (ACF). For an ARIMA (2,1,0) the ACF can take on any of four fundamental forms which vary according to the values of ϕ_1 and ϕ_2. These forms are shown in figure 2.

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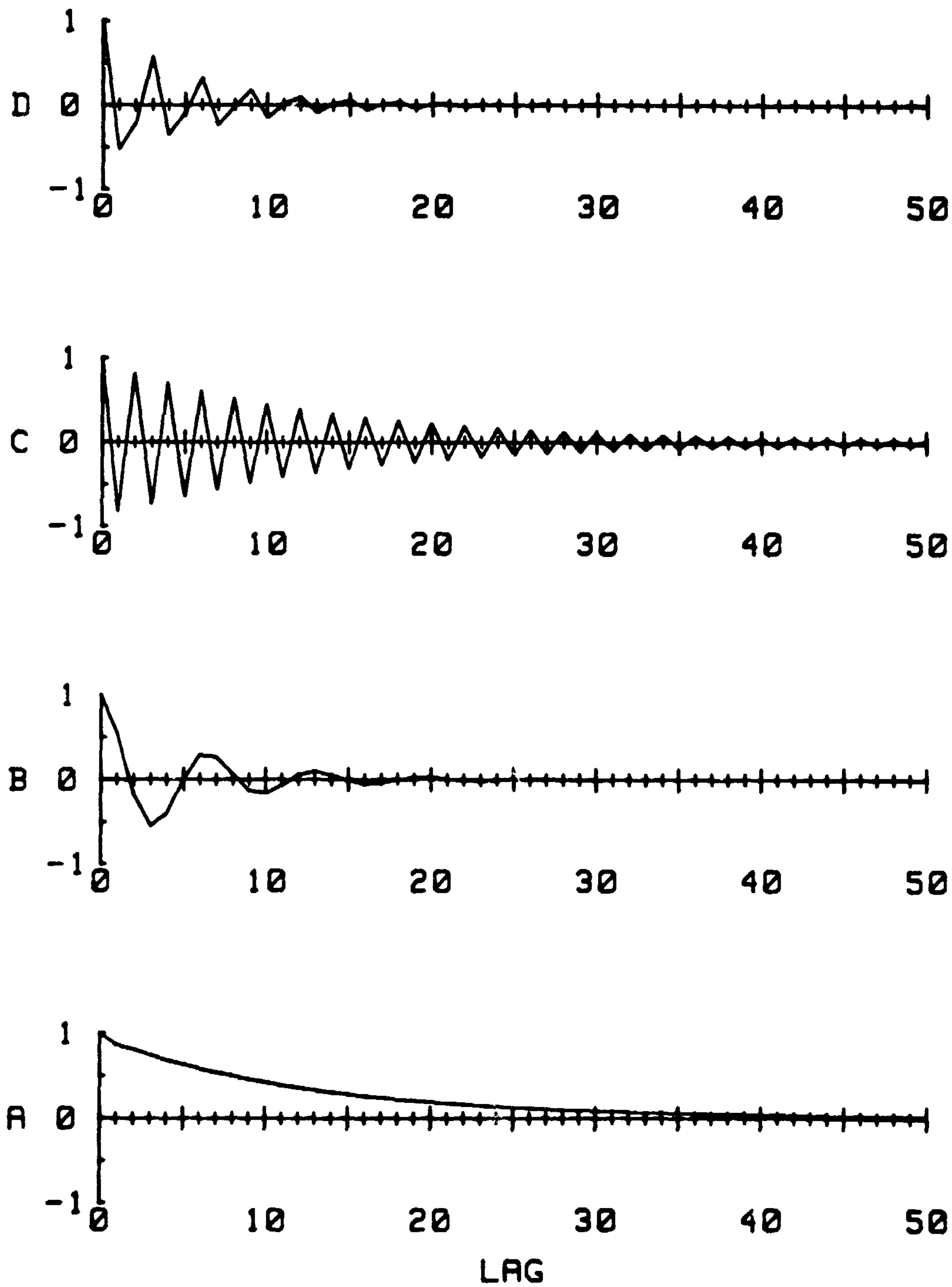


Figure 2. Examples of the four major different forms possible in an Autocorrelation Function of an ARIMA (2,1,0) model. Letters are keyed to areas of figure 5.

Other models with some other value of p (i.e. $p \neq 2$) would show distinctive forms of the ACF. The ACF of a model with $p = 1$ could be confused for those shown since it is equivalent to an ARIMA (2,1,0) with $\phi_2 = 0$. However, each of these alternative possibilities can be detected through the use of the second item of diagnosis, the partial autocorrelation function.

Partial autocorrelation is closely analogous to classical partial correlation. A simple example will show the value of its use. Suppose it is found that adjacent observations tend to be highly autocorrelated. Thus, point x influences point x + 1 while point x + 1 influences point x + 2. It is easy to see that point x will show a relation to point x + 2 simply due to the carry-over effect through point x + 1 even if no actual two step autocorrelation exists. In order to test for true two step autocorrelation, it is first necessary to remove the effect of the one step autocorrelation carry-over. Such correction produces the partial autocorrelation at lag two. Similar corrections are done for each lag in order to remove the effects of autocorrelation at lower lags. The resulting values, when plotted versus the appropriate lag is called the partial autocorrelation function (PACF).

Representative PACF's of ARIMA (2,1,0) models are shown in figure 3. In general, the PACF of an ARIMA (p,d,q) will have p-many significant values followed by values not significantly different from zero. It is the combination of these forms of the PACF together with an ACF as in figure 2 which is diagnostic of an ARIMA (2,d,0). Comparable diagnostic tools are available for other models and further details can be found in Box and Jenkins (1970).

Following the diagnostic stage, estimates of the values of the ϕ's

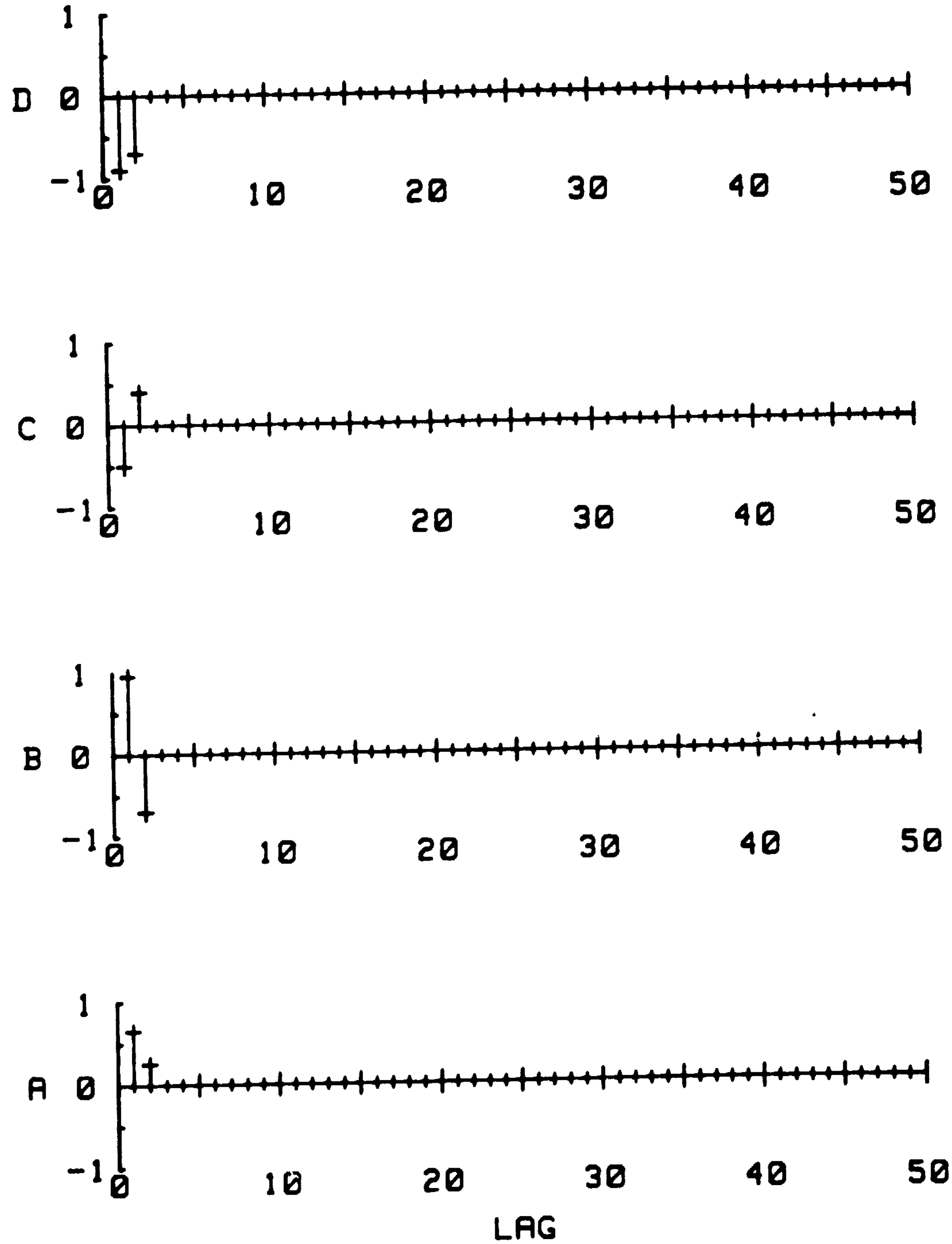


Figure 3. Examples of the four major different forms possible in a Partial Autocorrelation Function of an ARIMA (2,1,0) model. Letters are keyed to areas of figure 5.

and Θ's are obtained using a least squares method which yields an approximate maximum likelihood solution. The technique is iterative and is most efficient if reasonable preliminary estimates are used as starting values. For the ARIMA (2,1,0) these can be obtained from the first two values of autocorrelation (that at lags 1 and 2, labelled ρ_1 and ρ_2 using the following equations

$$\begin{aligned} \phi_1 &\sim \rho_1(1-\rho_2)/(1-\rho_1^2) \\ \phi_2 &\sim (\rho_2-\rho_1^2)\,/\,(1-\rho_1^2) \end{aligned} \tag{13}$$

Certain values of ϕ_1 and ϕ_2 are not feasible in that they can only arise from a non-stationary process, that is one for which a mean value does not exist. Indeed, it appears that traverses of elevation do represent a non-stationary process; however, slopes, the series of interest in this study, are almost surely stationary. Three inequalities define the admissible region for the parameters ϕ_1 and ϕ_2 which will yield stationary slope series

$$\begin{aligned} \phi_2 + \phi_1 &< 1 \\ \phi_2 - \phi_1 &< 1 \\ -1 < \phi_2 &< 1 \end{aligned}$$

this means the parameters ϕ_1 and ϕ_2 must fall within the triangular region shown in figure 4.

The four types of ACF and PACF shown in figures 2 and 3 arise when ϕ_1 and ϕ_2 take on specific values. These can best be seen in figure 5. In this figure the parabola corresponds to the locus of points satisfying

$$\phi_1^2 + 4\phi_2 = 0 \tag{15}$$

Figure 4. Region (within dashed triangle) representing the values of phi(1) and phi(2) which yield stationary ARIMA (2,1,0) models.

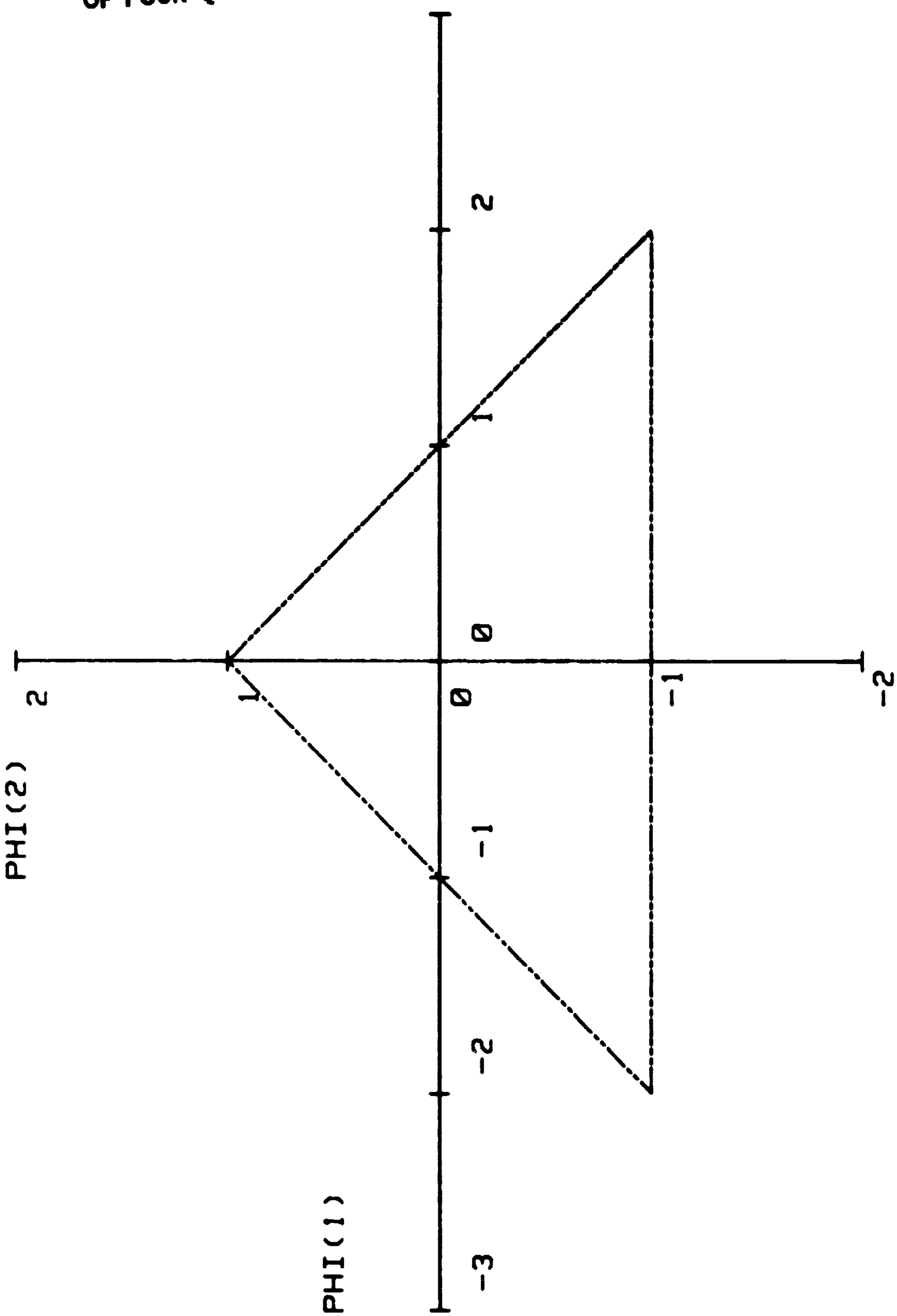
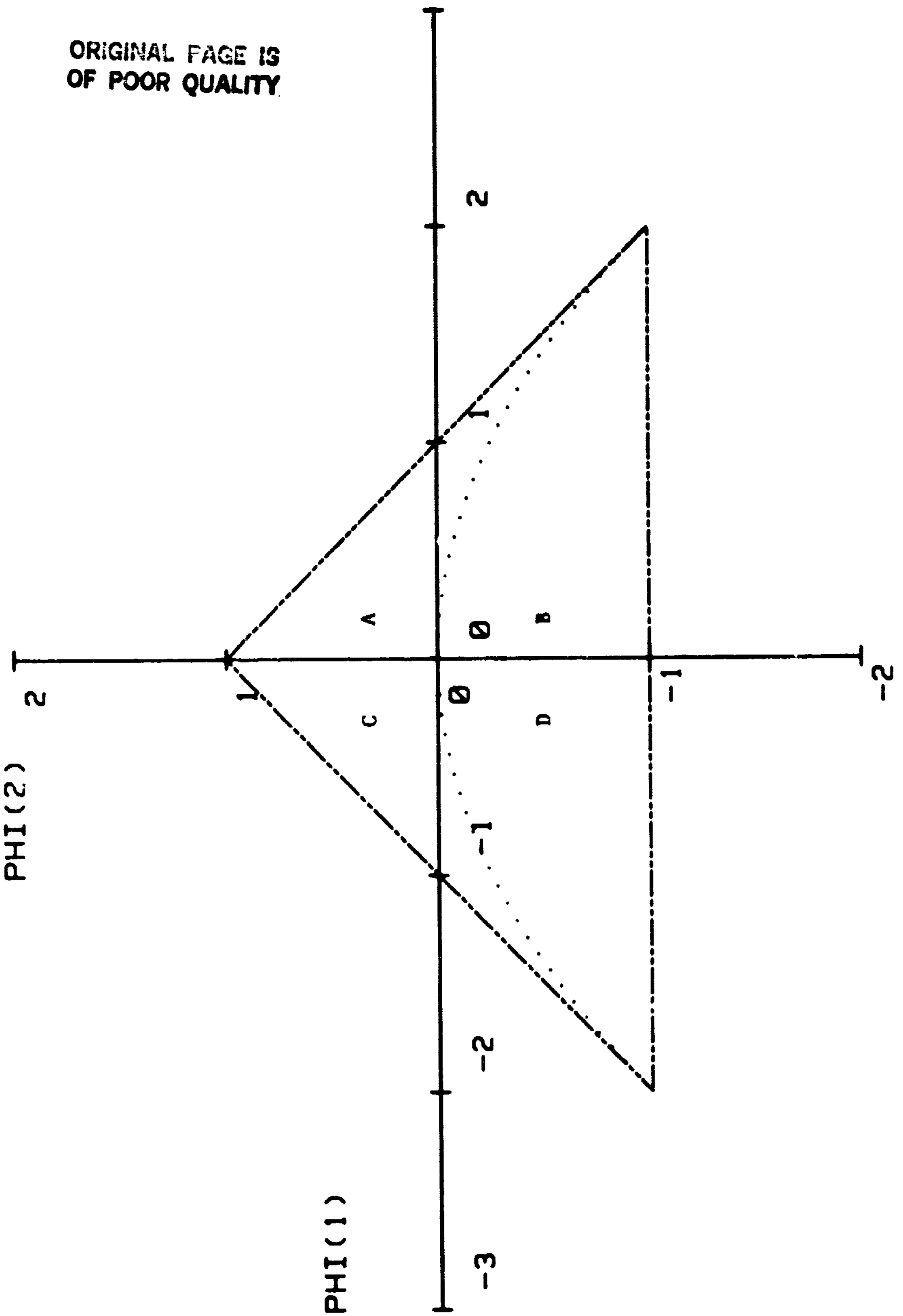

PHI(2)
PHI(1)
2
1
0
-1
-2
-3

Figure 5. Regions within which each of the forms of ACF and PACF shown in figures 2 and 3 can be observed.


PHI(2)
PHI(1)
A
B
C
D
2
1
Ø
-1
-2
-3

Within the lower (shaded) region the ACF's are more complicated. The parameters will plot in this region whenever the roots of the equation

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 = 0 \tag{16}$$

are complex. When this occurs the process will display a pseudo-periodic behavior.

Not all values of ϕ_1 and ϕ_2 are likely to be encountered in this study even within the admissible region (Figure 4). It is probably reasonable to assume that as constants of proportionality representing the effects of slope wash and creep, the values of a and b ought to express the proportional effects of these processes and thus fall in the range 0% to 100% (i.e. 0.0 to 1.0). If so then only the region shaded in figure 6 should be observed to occur in slope series. An even greater constraint will apply if we assume that a and b together should not provide more than 100% of the proportional effect, that is:

$$a + b < 1 \tag{17}$$

It is quite conceivable that they could provide less than 100% of the proportional effect since we allow other agents (tectonics, mass wasting, climate change, etc.) as represented by A(X) to also have an influence on slope forms. Thus, it would appear that we should only expect parameter values within the area shown in figure 7. The extent to which this turns out to be the case is thus a measure of the appropriateness and correctness of the slope process/form relation stated above.

Another interesting point is to observe that specific values of ϕ_1 and ϕ_2 once estimated can be used to predict values of E(X). The quality of the prediction to be expected can be measured and is described

Figure 6. Region within which estimates of phi(1) and phi(2) should fall if those parameters are in fact estimates of geomorphic process rates for slope wash (b) and creep (a). Also shown (dashed line) is the line along which a=b.

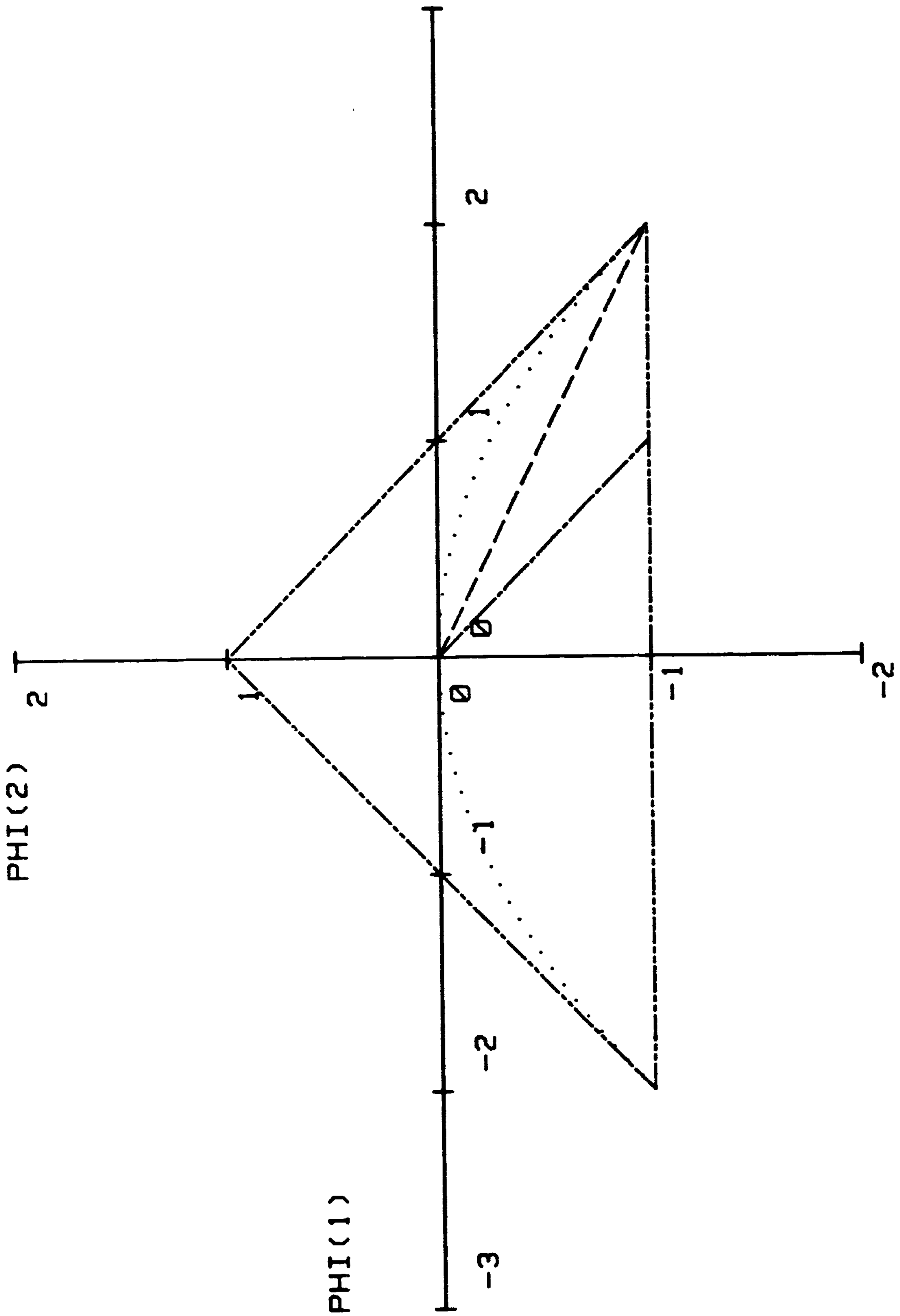
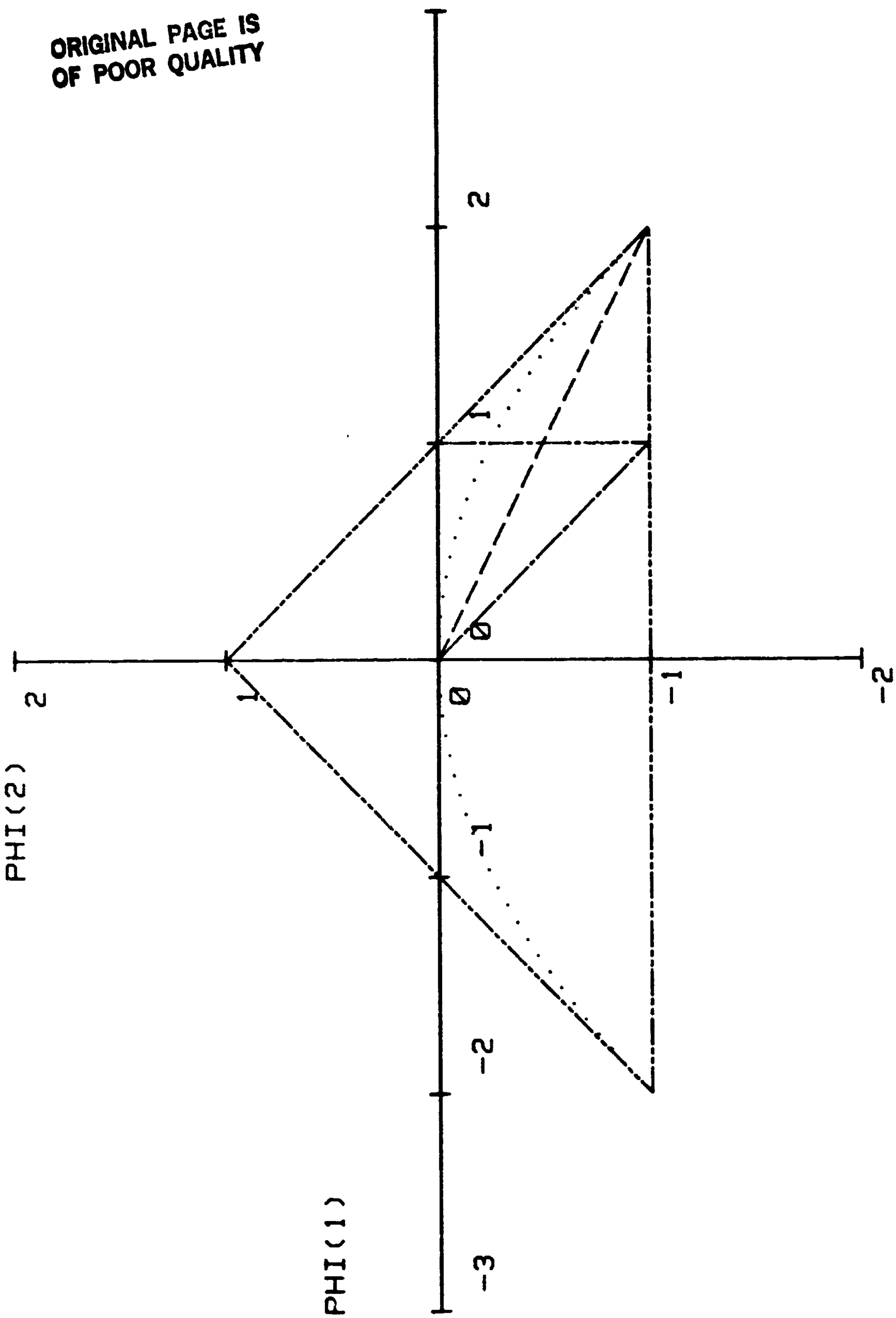

PHI(2)
PHI(1)
2
1
Ø
-1
-2
-3

Figure 7. Region within which estimates will occur if the parameters are constrained such that the total process rate (slope wash and creep together) does not exceed 100%.


PHI(1)
PHI(2)
-3
-2
-1
Ø
1
2
-2
-1
Ø
1
2

by the percent variance (of E(X)) explained by the model

$$E(X) = \phi_1 \; E(X-1) + \phi_2 \; E(X-2)$$

the remaining variance is attributed to the additional error term A(X). Thus, the variance of E(X) depends upon that of A(X) according to the equation

$$\sigma_E^2 = \frac{\sigma_A^2}{1 - \rho_1\phi_1 - \rho_2\phi_2} \tag{18}$$

or, strictly in terms of ϕ's

$$\sigma_E^2 = \left(\frac{1 - \phi_2}{1 + \phi_2}\right) \frac{\sigma_A^2}{\{(1-\phi_2)^2 - \phi_1^2\}} \tag{19}$$

Thus, exactly as would be expected, the percent variance explained by these processes increases as the proportional effect increases and is zero when their effect is zero. Contours of percent variance explained are shown in figure 8. As can be seen, the proportional effects of the processes must be quite large before the percent variance explained gets close to 100%.

The final point to consider is the effect upon estimates of ϕ_1 and ϕ_2 of errors in collecting data on slope. If the added error constitutes a white noise series, W(X) uncorrelated with the original series (in particular, uncorrelated with the A(X)) then the resulting series will be

$$Z(X) = E(X) + W(X) \tag{20}$$

The resulting model will be of the form (Box and Jenkins, 1970, p. 121)

$$\phi(B) \; \nabla^d Z(X) = A(X) + \phi(B) \; \nabla^d W(X) \tag{21}$$

Figure 8. Contours of equal percent variance explained by the ARIMA (2,1,0) model. Contour interval is 20%; the innermost contour line is the 10% value.

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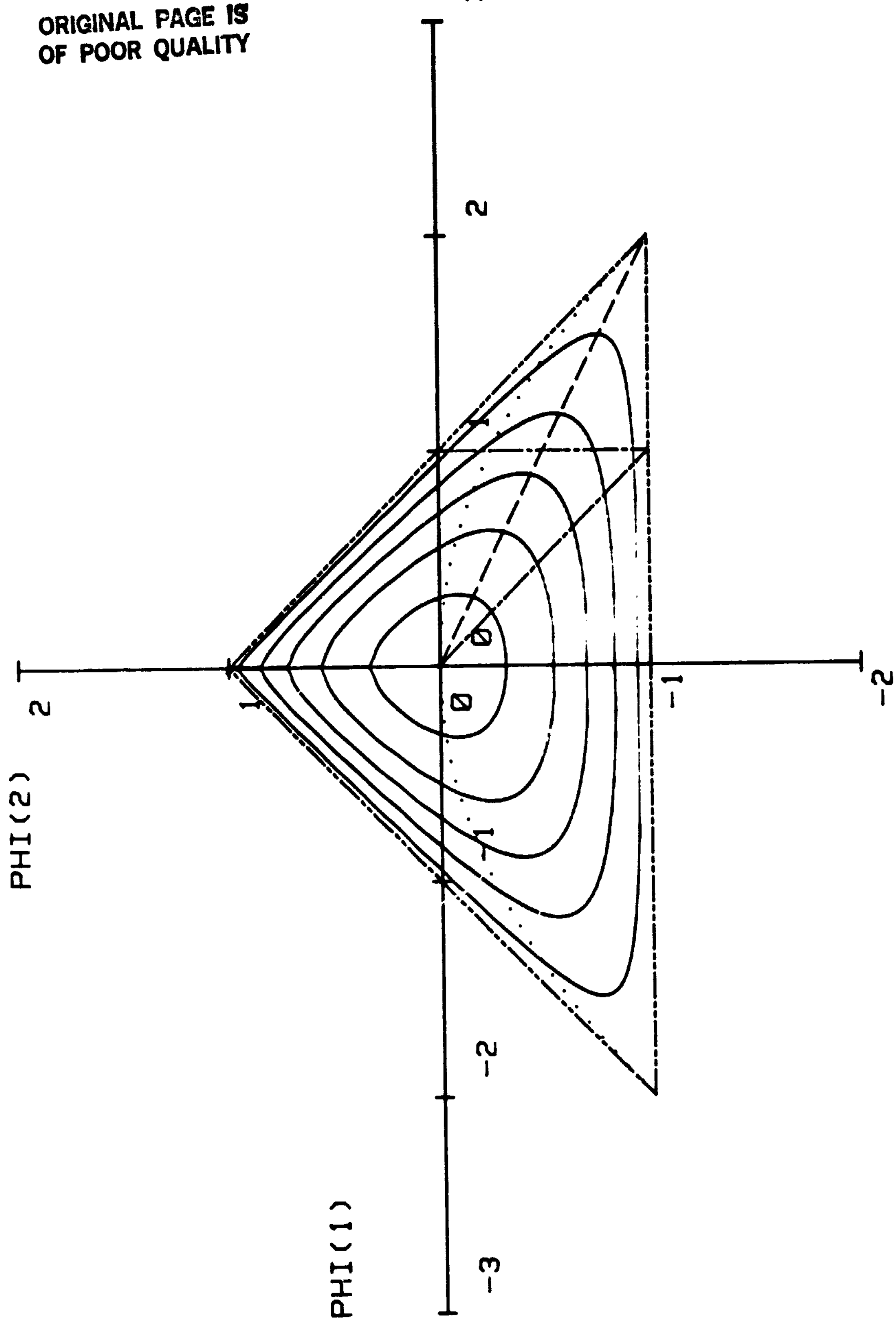

Where $\phi(B)$ is the same polynomial as given in equation 16 and ∇^d follows the definition of difference operator given earlier. This yields a mixed ARIMA model of order (2,1,3). Thus, it should be very obvious if any significant errors are introduced during the data collection process.

Such a process would have an autocovariance function which would be the sum of the autocovariance of the original series plus that of the series

$$\begin{aligned} V(X) &= \nabla^d W(X) \\ \gamma(Z) &= \gamma(E) + \gamma(V) \end{aligned} \tag{22}$$

and $\gamma(V)$ would consist of a value of -0.5 at lag 1 and would be zero everywhere else. Thus, it could be expected that whenever significant errors are introduced in data collection the ACF will show the error. The value of lag one will be small (less than 0.5) and the ACF will otherwise show a normal decay from a value 0.5 greater than that.

III. METHODS

The physiographic provinces chosen for this study are indicated in figure 1 and Table I. Two provinces which could have been included but which were not due to the limitation to a total of eight were the Coastal Plain and the Central Lowland. These seemed most reasonable to avoid in this first study because it seemed possible that they tend to be more strongly affected by depositional processes. Thus, there was some uncertainty whether the ARIMA (2,1,0) creep/slope wash model would apply. In the case of the Coastal Plain there is a great deal of flood plain formation in addition to the marine deposition (and erosion) processes. The Central Lowland has so recently been glaciated that the deposition of thick sequences of till can be expected to exert a significant control upon the form of the land. The effects of normal erosional processes may not be a significant factor in shaping the land yet.

Choice of specific sampling sites within the chosen physiographic provinces was limited by four constraints. Within each region three sites were desired. It was assumed that the sites should represent, to the extent practical, the diversity of physiography to be found within the province. An important guide used to help in this choice was the published list of 100 diverse physiographic sites throughout the U.S. Whenever possible, sites were chosen from this list (Upton, 1955).

The scale at which an area is mapped or at which the map is published, will influence the accuracy (and precision) of the data obtained from that map. In the case of topographic information the horizontal accuracy is directly controlled. The vertical accuracy is also influenced because the density of contours is limited, hence so is the contour interval. This in turn will control the vertical accuracy (U.S.G.S.,1970). For

this study, only maps of one scale (1:24000) were used. Thus, only where standard 7½' quadrangle maps were available could sites be selected for analysis.

A further guide to selection of sites is taken from the detailed breakdown of physiographic provinces into sections. These are contiguous regions of similar physiography to some extent distinctive from other sections in the province. Sections into which the eight provinces of interest are divided are listed in table II and are shown by light lines on figure 1. Wherever possible the three sites within a province were taken from three different sections. Four of these provinces have only two sections.

a. Piedmont Province

b. Blue Ridge Province

c. Ozark Plateaus Province

d. Ouachita Province

If more sites were still available than could be used the selection was made randomly. There were also a number of sites that could not be selected using the methods outlined above. These were chosen more or less arbitrarily. Three constraints were applied to this selection. The 7½' map had to be readily available, the site could not be urbanized and the site could not be predominantly in an alluvial plain or other depositional setting. These additional sites are listed in table III.

Three-dimensional plots of the chosen sites showing an area of three by three quadrangles surrounding the sampling point were prepared in order to examine the areas. This allowed a simple means to familiarize oneself with the physiography and to thus ensure that the chosen quadrangle was within the province expected and that the region was reasonably

Table II. Sections into which the eight physiographic provinces studied are divided.

Physiographic province		Section
1. Interior Low Plateaus	a	Highland rim section
	b	Lexington Plain
	c	Nashville Basin
	d	(possible western section)
2. New England province	a	Seaboard Lowland section
	b	New England Upland section
	c	White Mountain section
	d	Green Mountain section
	e	Taconic section
3. Piedmont province	a	Piedmont Upland
	b	Piedmont Lowlands
4. Blue Ridge province	a	Northern section
	b	Southern section
5. Ozark Plateaus	a	Springfield-Salem plateau
	b	Boston "Mountains"
6. Valley and Ridge province	a	Tennessee section
	b	Middle section
	c	Hudson Valley
7. Appalachian Plateaus	a	Mohawk section
	b	Catskill section
	c	Southern New York section
	d	Allegheny Mountain section
	e	Kanawha section
	f	Cumberland Plateau section
	g	Camberland Mountain section
8. Ouachita province	a	Arkansas Valley
	b	Ouachita Mountains

Table III. Additional sample sites not chosen from Upton (1955).

Quadrangle	State	Physiographic province
Alexandria	PA	Valley and Ridge
Fidelity	MO	Ozark Plateaus
Horseshoe Mtn.	AK	Ouachita Mountains
Lavaca	AK	Ouachita Mountains
Mena	AK	Ouachita Mountains
Saugerties	NY	Valley and Ridge
Sherando	VA	Blue Ridge

representative of the relief of the chosen physiographic section.

Earlier investigations had used four traverses oriented at 45° to one another along the principal compass directions. This yields replicates of the measure of physiographic complexity within each quadrangle which in turn allows us to test whether it varies significantly from site to site within a province. These orientations should also be adequate to detect the greatest diversity of topographic structure. Thus, this same sampling plan was continued in this study.

These earlier studies had consisted of traverses of points spaced 2 mm (= 48 m) apart for a distance of 50 points (= 2400 m). This did not seem adequate to ensure covering a sufficiently long part of the area to obtain a significant portion of the physiographic diversity. Thus, for this study a traverse three times as long (7200 m) was obtained in each of the four directions.

The traverses were sampled at 1 mm (= 24 m) because it was felt the earlier samples may have failed to pick up all of the available topographic variation. It was assumed that this was the practical limit of resolution and the horizontal map accuracy hardly warrants any tighter sampling.

Elevations were estimated to the nearest foot* and recorded by hand on individual data sheets. Also recorded was the operator's name, beginning and ending times, name and location of quadrangle, contour interval and any problems that arose including errors in the maps themselves. The traverse positions were determined through the use of a transparent overlay (Figure 9) which was centered on the quadrangle. Both were taped down on a light table to facilitate the work. All raw data are on file with the author.

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* Contours are given in feet on the maps and so metric units were not recorded.

Figure 9. Sampling grid used in collectin traverse data. This is a reproduction at about one-third original scale.

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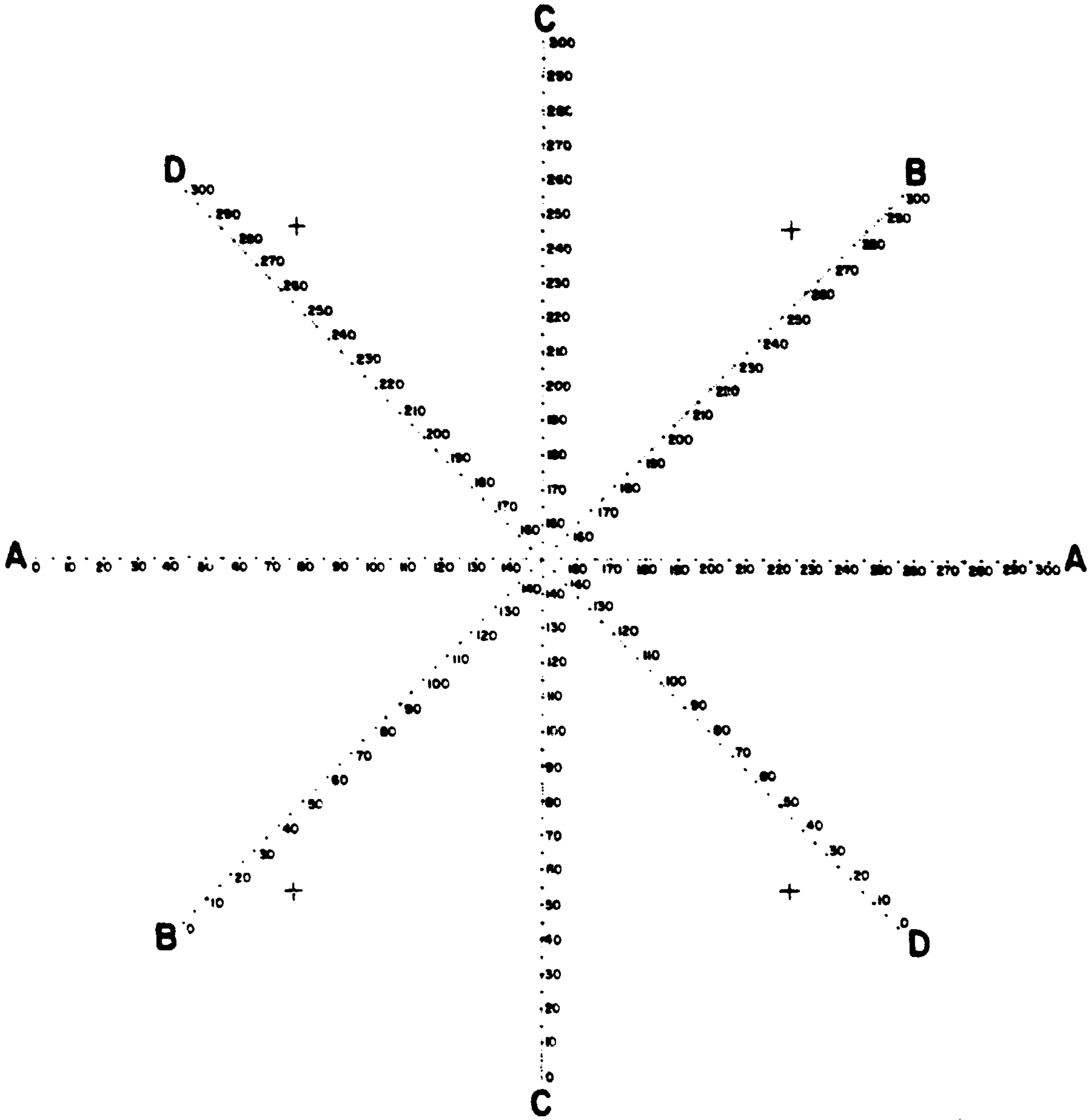


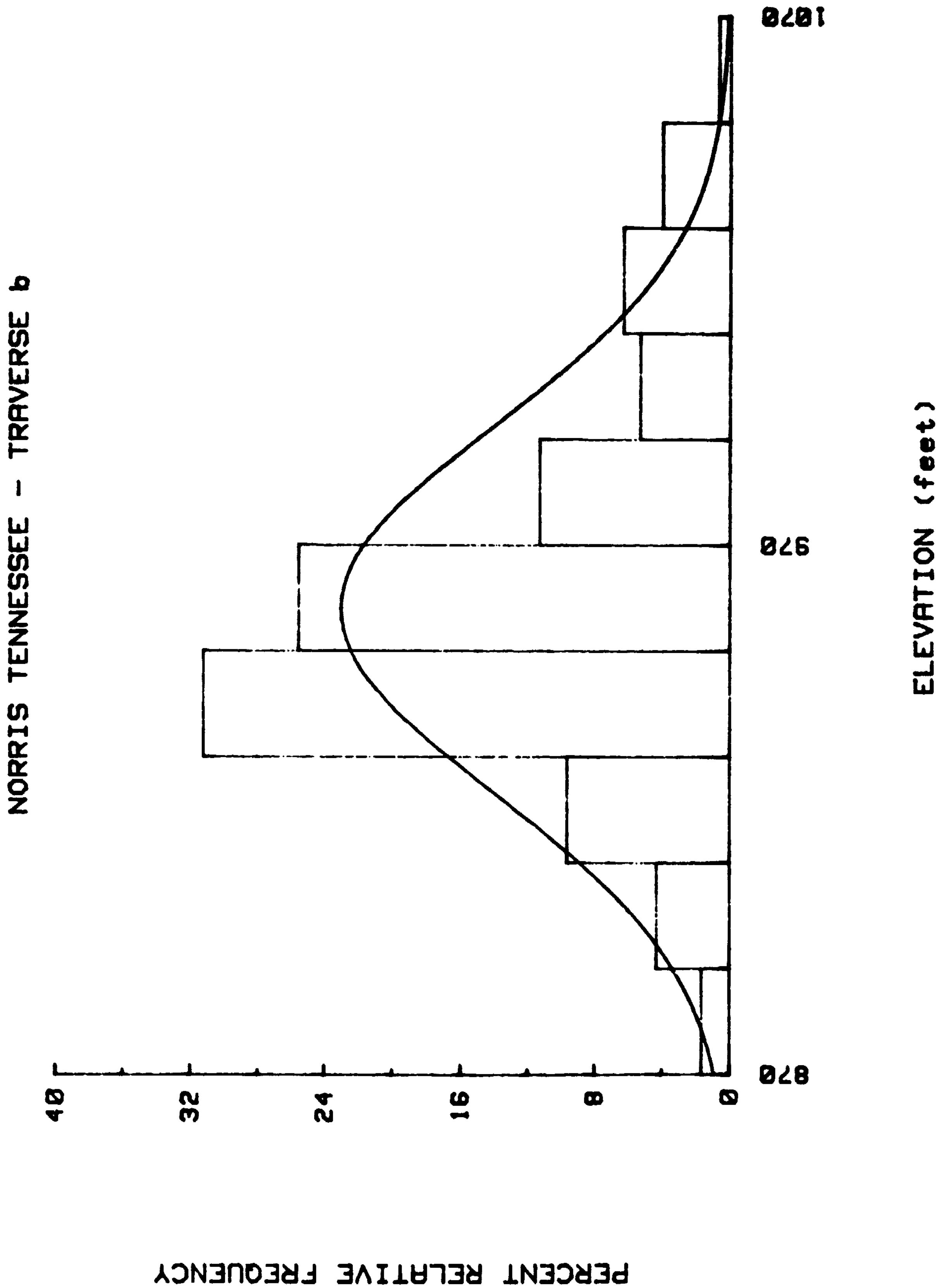
SAMPLING GRID
AUTOCORRELATION STUDY
1mm SPACING
300 POINT TRAVERSES

Once recorded the data were keyed into the HP9845B minicomputer and stored on floppy disk. Initial accuracy checks included proof-reading the data followed by computation of basic statistics including Fishers (1953) g_1 and g_2 and the χ^2 measure of goodness of fit to the normal distribution which in most cases appeared tc be the most reasonable assumption of the underlying frequency distribution. A typical histogram is shown in figure 10, these were produced for each traverse and examined carefully for outliers that could indicate erroneous data. A number of points were corrected in this way. Summary statistics of raw traverses of elevation can be found in the appendix. Data were easily corrected using the simple programs available on the HP. In some cases it was necessary to refer to the original maps to estimate the correct data. In other cases referring to the raw data sheets cleared up the problem. Not uncommonly the error was simply a typographical one in which, for example, 4160 was keyed in instead of 2160.

Following this initial data checking the data were transferred by phone line to the KSU Burroughs computer system. There the ACF's and PACF's were computed for the original series and the first and second differences. In addition, a line-printer generated plot of the data was made. This was examined for any obvious points which were erroneous values. A significant number of mistakes were caught using this method.

With the ACF's and PACF's available the next step was to identify the model. In this case it was already expected that the model would be an ARIMA (2,1,0). Thus, the "identification" step was also a check of the reasonableness of the initial assumption. The need for a first difference in the model was checked by the decay of the ACF of the original series. A slow decay is a good indication that a difference is needed.

Figure 10. A typical histogram of elevations collected from one traverse. Line gives the best fit normal distribution.


NORRIS TENNESSEE - TRAVERSE b
ELEVATION (feet)
870
970
1070
PERCENT RELATIVE FREQUENCY
0
8
16
24
32
40

The ACF of the first difference was then checked to see that it followed the patterns shown in figure 2, parts A or B. The PACF of the first difference was checked to see if it followed the desired pattern (figure 3). Only two values should be significant, those at lags 1 and 2. The first should be positive, the second negative. Any departures from the expected pattern were noted and, if appropriate, alternative models were identified.

In every case the ARIMA (2,1,0) model seemed to be the appropriate one or at the very least (in a very few cases) was a sufficiently reasonable null hypothesis. For each series preliminary estimates of ϕ_1 and ϕ_2 were obtained from the listed values of $\hat{\rho}_1$ and $\hat{\rho}_2$ (see Table IV). Whenever the preliminary estimates did not correspond to the expected model - this was especially evident if $\hat{\phi}_2$ was positive but also could be detected if $\hat{\phi}_1$ was small (less than 0.5) - the data were checked for possible errors. A number of corrections were made at this stage. Using these preliminary estimates the actual values of the coefficients were obtained (Table V) using the least squares method mentioned previously. Confidence limits on those values were also obtained. In most cases the preliminary and final estimates corresponded quite closely (Figure 11). Where these values did not correspond the original data were checked to determine if this were due to an error. This was found to be the case in most instances. However, some unexplained large discrepancies still remain. Thus, one should not rely too heavily upon the preliminary estimates when accurate estimates of ϕ_1 and ϕ_2 are essential.

The reasonableness of the computed model was tested using several diagnostic tools. First the residuals, R, were computed by subtracting values predicted using this model (with the coefficients ϕ_1 and ϕ_2

Table IV. Initial estimates of autocorrelation and preliminary coefficient estimates derived from them using equation 13.

Province	Quadrangle	State		$\nabla^1 \rho_1$	$\nabla^1 \rho_2$	∇^1 Prelim. ϕ_1	∇^1 Prelim. ϕ_2
Interior Low	Mammoth Cave	KY	a	.7597	.5481	.8119	-.0687
			b	.7073	.4343	.8007	-.1320
			c	.6965	.4370	.7616	-.0934
			d	.6937	.3952	.8087	-.1658
	Hillsboro	KY	a	.6735	.3460	.8061	-.1969
			b	.5582	.1809	.6642	-.1898
			c	.6623	.3123	.8114	-.2251
			d	.5016	.1498	.5667	-.1333
	Rover	TN	a	.6543	.3700	.7208	-.1016
			b	.7535	.5620	.7635	-.0133
			c	.7208	.5477	.6786	.0586
			d	.7410	.5679	.7101	.0417
New England	Ayer	MA	a	.5069	.2694	.4984	.0168
			b	.6711	.3609	.7804	-.1628
			c	.8175	.6998	.7399	.0949
			d	.6772	.4428	.6970	-.0292
	Kingston	RI	a	.6647	.3978	.7171	-.0789
			b	.4549	.1794	.4707	-.0347
			c	.6663	.3349	.7970	-.1961
			d	.5840	.2384	.6750	-.1558
	Brandon	VT	a	.7764	.6106	.7611	.0196
			b	.6756	.5740	.5295	.2163
			c	.7075	.4735	.7458	-.0542
			d	.3504	.4447	.6729	.0522
Piedmont	Warm Springs	GA	a	.6835	.3384	.8487	-.2417
			b	.7249	.5114	.7464	-.0297
			c	.6341	.3677	.6706	-.0575
			d	.6689	.4111	.7129	-.0657
	Patterson	NJ	a	.7544	.5731	.7474	.0092
			b	.7477	.5046	.8400	-.1235
			c	.6205	.3077	.6985	-.1257
			d	.7515	.5397	.7948	-.0576
	Washington West	DC	a	.5338	.2092	.5903	-.1059
			b	.6363	.3440	.7014	-.1023
			c	.6733	.3579	.7908	-.1746
			d	.6792	.3196	.8579	-.2631

Province	Quadrangle	State		$\nabla^1\rho_1$	$\nabla^1\rho_2$	∇^1 Prelim. ϕ_1	∇^2 Prelim. ϕ_2
Blue Ridge	Mount Mitchell	NC	a	.8078	.6789	.7465	.0759
			b	.8430	.7278	.7930	.0593
			c	.6686	.3641	.7689	-.1500
			d	.8226	.6811	.8113	.0137
	Strasburg	VA	a	.7714	.6113	.7377	.0420
			b	.65	.33	.7541	-.1602
			c	.73	.54	.7189	.0152
			d	.81	.66	.8088	.0113
	Sherando	VA	a	.8600	.77	.7596	.1167
			b	.87	.76	.8589	.0128
			c	.8386	.7163	.8017	.0440
			d	.8381	.7066	.8274	.0149
Ozark Plateaus	Ironton	MO	a	.7758	.6144	.7514	.0315
			b	.8096	.6455	.8330	-.0289
			c	.8063	.7079	.6731	.1651
			d	.7359	.5373	.7427	-.0093
	Saint Paul	AR	a	.7972	.6392	.8018	-.0171
			b	.8401	.7342	.7589	.0966
			c	.6997	.4434	.7630	-.0905
			d	.7335	.6157	.6102	.1681
	Fidelity	MO	a	.65	.19	.9117	-.4026
			b	.58	.33	.5856	-.0096
			c	.43	.29	.3746	.1289
			d	.6140	.2679	.7092	-.1626
Ouachita Mtns.	Horseshoe Mtn.	AR	a	.7928	.6232	.8042	-.0144
			b	.7832	.6114	.7873	-.0052
			c	.8441	.6903	.9093	-.0772
			d	.8074	.6800	.7422	.0807
	Mena	AR	a	.6807	.4062	.7532	-.1065
			b	.6500	.3700	.7081	-.0909
			c	.5500	.2400	.5993	-.0896
			d.	.64	.32	.7371	-.1518
	Lavaca	AR	a	.77	.49	.9646	-.1528
			b	.73	.66	.5314	.2721
			c	.75	.63	.6343	.1543
			d	.75	.53	.8057	-.0743

Province	Quadrangle	State		$\nabla^1\rho_1$	$\nabla^1\rho_2$	∇^1 Prelim. ϕ_1	∇^2 Prelim. ϕ_2
Valley and Ridge	Norris	TN	a	.7677	.5667	.8101	-.0552
			b	.7319	.5092	.7736	-.0570
			c	.8167	.6251	.9195	-.1258
			d	.7896	.5610	.9206	-.1659
	Alexandria	PA	a	.7481	.5204	.8148	-.0891
			b	.6833	.4332	.7265	-.0632
			c	.7807	.5376	.9244	-.1841
			d	.7071	.4970	.7113	-.0060
	Saugerties	NY	a	.6427	.2760	.7928	-.2335
			b	.7318	.4968	.7928	-.0834
			c	.7186	.3846	.9144	-.2725
			d	.6330	.3258	.7121	-.1250
Appalachian Plateaus	Ithaca West	NY	a	.7323	.5201	.7578	-.0349
			b	.6572	.2572	.8593	-.3075
			c	.5511	.8029	.1560	.7169
			d	.7168	.4288	.8421	-.1748
	Fayetteville	WV	a	.6652	.5825	.4985	.2560
			b	.8215	.6916	.7792	.0515
			c	.7368	.6223	.6088	.1738
			d	.7106	.5351	.7027	.0241
	Whitwell	TN	a	.8977	.8287	.8053	.1053
			b	.4471	.2816	.4014	.1021
			c	.6981	.4376	.7658	-.0970
			d	.8060	.6743	.7493	.0704

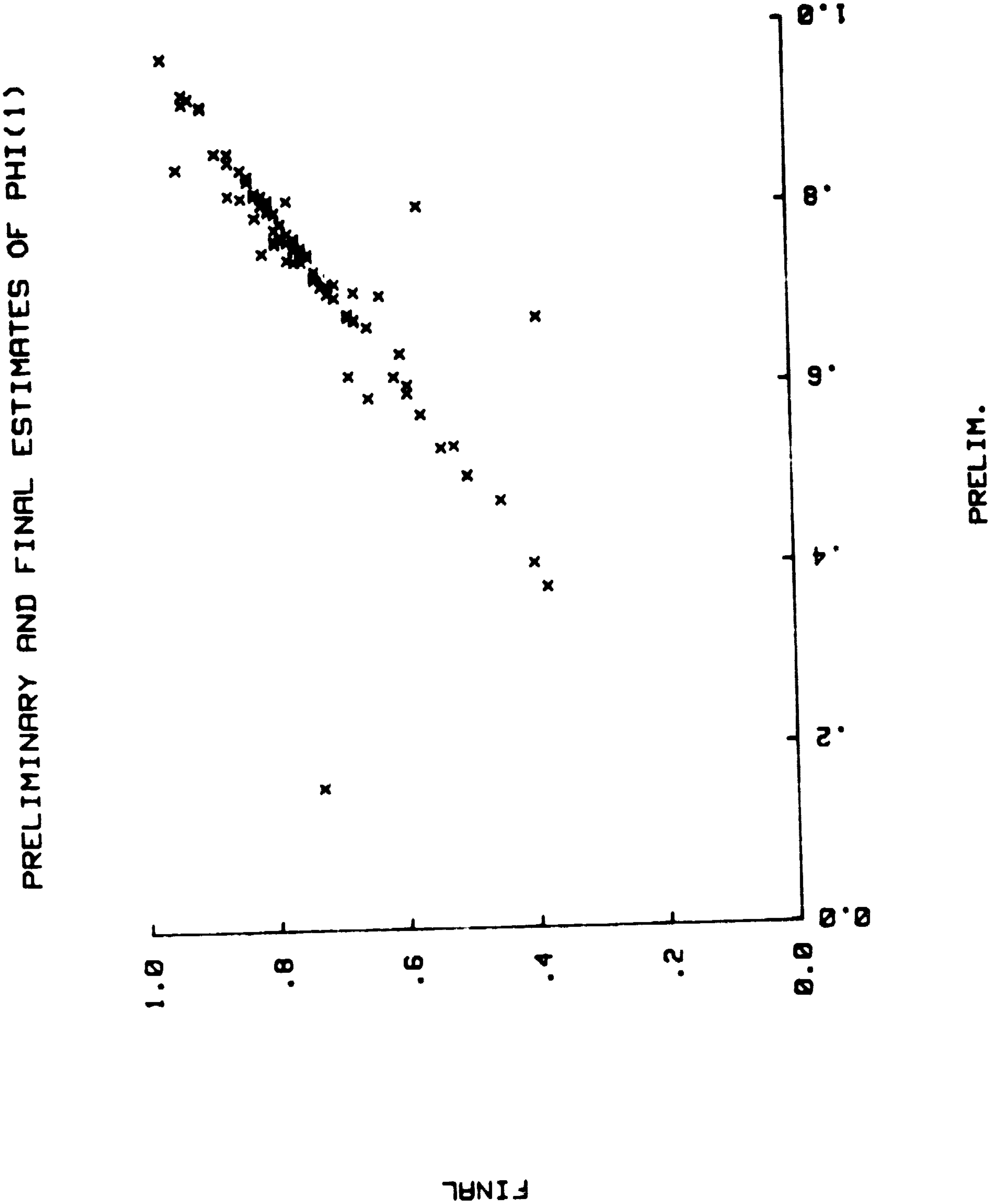
Table V. Final estimates of coefficients ϕ_1 and ϕ_2 for the 96 traverses. Also listed are the upper and lower 95% confidence limits for the coefficients.

Province	Quadrangle	State		ϕ_1 Upper	ϕ_1	ϕ_1 Lower	ϕ_2 Lower	ϕ_2	ϕ_2 Upper
Piedmont	Warm Springs	GA	a	0.97	0.86	0.74	-0.35	-0.24	-0.13
			b	0.86	0.74	0.63	-0.14	-0.03	0.09
			c	0.79	0.67	0.55	-0.17	-0.06	0.06
			d	0.83	0.71	0.60	-0.18	-0.06	0.05
	Paterson	NJ	a	0.93	0.81	0.69	-0.19	-0.07	0.05
			b	0.96	0.84	0.73	-0.24	-0.12	-0.05
			c	0.74	0.63	0.53	-0.18	-0.08	0.03
			d	0.92	0.80	0.68	-0.17	-0.05	0.07
	Washington West	DC	a	0.71	0.59	0.48	-0.22	-0.11	0.01
			b	0.82	0.71	0.60	-0.22	-0.11	0.01
			c	0.91	0.79	0.68	-0.29	-0.17	-0.06
			d	0.97	0.86	0.75	-0.38	-0.26	-0.15
Blue Ridge	Mount Mitchell	NC	a	0.86	0.75	0.63	-0.05	0.08	0.19
			b	0.91	0.80	0.68	-0.05	0.06	0.18
			c	0.89	0.77	0.66	-0.26	-0.15	-0.03
			d	0.93	0.81	0.69	-0.10	0.02	0.13
	Strasburg	VA	a	0.86	0.75	0.63	-0.07	0.04	0.16
			b	0.87	0.75	0.64	-0.27	-0.15	-0.04
			c	0.84	0.72	0.61	-0.10	0.01	0.13
			d	0.93	0.81	0.70	-0.10	0.02	0.14
	Sherando	VA	a	0.89	0.77	0.66	-0.01	0.11	0.22
			b	0.98	0.86	0.74	-0.10	0.02	0.14
			c	0.92	0.81	0.69	-0.07	0.05	0.16
			d	0.94	0.83	0.71	-0.10	0.02	0.13
Valley and Ridge	Norris	TN	a	0.93	0.81	0.70	-0.17	-0.06	0.06
			b	0.91	0.79	0.68	-0.18	-0.06	0.05
			c	1.03	0.92	0.80	-0.24	-0.12	-0.01
			d	1.03	0.92	0.80	-0.28	-0.16	-0.05
	Alexandria	PA	a	0.93	0.82	0.70	-0.20	-0.09	0.03
			b	0.84	0.73	0.61	-0.17	-0.06	0.06
			c	1.05	0.93	0.82	-0.30	-0.19	-0.08
			d	0.83	0.71	0.59	-0.12	-0.01	0.11

Province	Quadrangle	State		ϕ_1 Upper	ϕ_1	ϕ_1 Lower	ϕ_2 Lower	ϕ_2	ϕ_2 Upper
Valley and Ridge	Saugerties	NY	a	0.91	0.79	0.68	-0.35	-0.23	-0.12
			b	0.91	0.79	0.68	-0.20	-0.08	0.03
			c	1.05	0.93	0.82	-0.39	-0.28	-0.17
			d	0.81	0.70	0.59	-0.23	-0.12	-0.01
Appalachian Plateaus	Ithaca West	NY	a	0.91	0.79	0.68	-0.12	-0.04	0.11
			b	1.00	0.88	0.77	-0.41	-0.30	-0.18
			c	0.84	0.73	0.62	-0.43	-0.32	-0.21
			d	1.05	0.94	0.82	-0.28	-0.17	-0.06
	Fayetteville	WV	a	0.61	0.50	0.39	0.14	0.25	0.36
			b	0.90	0.78	0.66	-0.06	0.05	0.17
			c	0.72	0.61	0.49	0.06	0.17	0.29
			d	0.78	0.67	0.55	-0.05	0.06	0.18
	Whitwell	TN	a	0.89	0.77	0.66	0.02	0.14	0.25
			b	0.51	0.40	0.28	-0.01	0.11	0.22
			c	0.89	0.78	0.66	-0.21	-0.09	0.02
			d	0.87	0.75	0.63	-0.04	0.07	0.19
Interior Low	Mammoth Cave	KY	a	0.98	0.86	0.75	-0.22	-0.11	0.01
			b	0.92	0.80	0.68	-0.25	-0.13	-0.02
			c	0.89	0.78	0.66	-0.21	-0.09	0.02
			d	0.95	0.84	0.72	-0.30	-0.19	-0.07
	Hillsboro	KY	a	0.91	0.80	0.68	-0.30	-0.19	-0.08
			b	0.77	0.65	0.54	-0.30	-0.18	-0.07
			c	0.92	0.81	0.70	-0.34	-0.22	-0.11
			d	0.69	0.57	0.46	-0.25	-0.14	-0.02
	Rover	TN	a	0.84	0.73	0.61	-0.23	-0.11	0.01
			b	0.88	0.76	0.65	-0.12	-0.01	0.11
			c	0.80	0.68	0.56	-0.06	0.06	0.18
			d	0.83	0.71	0.59	-0.07	0.04	0.16
New England	Ayer	MA	a	0.61	0.50	0.38	-0.10	0.02	0.13
			b	0.90	0.78	0.67	-0.28	-0.16	-0.05
			c	0.88	0.77	0.65	-0.03	0.09	0.21
			d	0.81	0.70	0.58	-0.14	-0.03	0.09
	Kingston	RI	a	0.85	0.73	0.61	-0.19	-0.07	0.05
			b	0.56	0.45	0.33	-0.13	-0.02	0.08
			c	0.69	0.57	0.46	-0.17	-0.05	0.07
			d	0.79	0.68	0.56	-0.27	-0.15	-0.04
	Brandon	VT	a	0.90	0.79	0.67	-0.10	0.02	0.14
			b	0.66	0.54	0.43	0.12	0.23	0.35
			c	0.86	0.75	0.64	-0.16	-0.05	0.06
			d	0.51	0.39	0.27	-0.20	-0.08	0.04

Province	Quadrangle	State		ϕ_1 Upper	ϕ_1	ϕ_1 Lower	ϕ_2 Lower	ϕ_2	ϕ_2 Upper
Ozark Plateaus	Ironton	MO	a	0.87	0.76	0.64	-0.08	0.04	0.15
			b	0.95	0.83	0.72	-0.14	-0.03	0.09
			c	0.79	0.67	0.56	0.05	0.16	0.28
			d	0.86	0.74	0.63	-0.12	-0.001	0.12
	Saint Paul	AR	a	0.93	0.82	0.70	-0.13	-0.02	0.09
			b	0.88	0.76	0.65	-0.02	0.01	0.21
			c	0.88	0.76	0.65	-0.20	-0.09	0.03
			d	0.79	0.68	0.56	0.01	0.12	0.23
	Fidelity	MO	a	1.01	0.90	0.79	-0.50	-0.39	-0.28
			b	0.78	0.65	0.53	-0.16	-0.04	0.08
			c	0.50	0.38	0.27	0.02	0.13	0.25
			d	0.84	0.72	0.61	-0.29	-0.17	-0.06
Ouachita Mountains	Horseshoe Mtn.	AR	a	0.92	0.80	0.69	-0.12	-0.01	0.11
			b	0.93	0.82	0.70	-0.14	-0.02	0.10
			c	1.01	0.90	0.78	-0.18	-0.06	0.05
			d	0.86	0.74	0.63	-0.03	0.08	0.20
	Mena	AR	a	0.87	0.76	0.64	-0.22	-0.10	0.02
			b	0.82	0.71	0.59	-0.19	-0.07	0.04
			c	0.48	0.59	0.70	-0.19	-0.07	0.04
			d	0.87	0.76	0.64	-0.27	-0.16	-0.49
	Lavaca	AR	a	1.07	0.96	0.84	-0.36	-0.24	-0.13
			b	0.64	0.52	0.41	0.18	0.29	0.40
			c	0.72	0.60	0.49	0.08	0.19	0.30
			d	0.92	0.80	0.69	-0.19	-0.07	0.04

Figure 11. Scatter diagram of preliminary estimates of phi(1) obtained from equation 13 plotted versus the final estimates obtained from a least square fit.


PRELIMINARY AND FINAL ESTIMATES OF PHI(1)
PRELIM.
FINAL
0.0
.2
.4
.6
.8
1.0

listed in Table V) from the values actually observed:

$$E^1(X) - \phi_1 E^1(X-1) - \phi_2 E^1(X-2) = R(X) \qquad (23)$$

The residuals should be white noise, i.e. have no remaining structure. This was tested by computing the ACF's and PACF's as previously. The ACF and PACF of the original (residual) series should show no significant values. The ACF of the first difference is expected to have a value of -0.5 at lag 1 and be not significantly different from zero otherwise. The PACF of the first difference is expected to decay to zero with the value at each lag k equal to -1/(k+1). The ACF of the second difference should have the values -0.67 at lag 1 and 0.17 at lag 2 and otherwise be not significantly different from zero. The PACF of the second difference should decay to zero following the function -2/(k+2). Each of these checks were performed and significant departures recorded.

An additional diagnostic is that the mean of the residual series should not be significantly different from zero. This was tested by a t statistic (Table VI). The "portmanteau" test of the ACF of the original residual series checks for systematic tendencies to deviate from zero which is more sensitive than simply checking the confidence limits. This test yields a statistic distributed as X^2 under the null hypothesis that there are no significant systematic tendencies to deviate from zero. The results of this test are also reported in table VI.

The fit of the model was also checked by examining a plot of the residuals (versus observation number). Suspicious patterns can be an indication of lack of fit. Such checks were also done, a typical plot of residuals is given in figure 12.

Finally, because it was expected that the coefficients should fall

Table VI. Results of first five tests of residuals from the ARIMA (2,1,0) model. Tests are explained in the text. An asterisk indicates the value exceeds the 95% confidence limit.

Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Interior Low	Mammoth Cave	KY	a	.07	57.3	-.56	-.71	.24
			b	.26	43.8	-.49	-.67	.22
			c	1.10	35.8	-.50	-.65	.11
			d	.01	52.9	-.52	-.69	.23
	Hillsboro	KY	a	.02	58.1	-.57	-.73	.28
			b	.40	72.8*	-.53	-.71	.27
			c	.16	49.3	-.52	-.68	.19
			d	.35	72.3*	-.57	-.75	.38*
	Rover	TN	a	.13	40.4	-.55	-.73	.35*
			b	.76	40.6	-.52	-.67	.15
			c	.44	39.1	-.50	-.67	.18
			d	.01	55.1	-.50	-.65	.13
New England	Ayer	MA	a	.11	68.5*	-.50	-.65	.07
			b	.25	67.3*	-.51	-.69	.24
			c	.27	67.5*	-.52	-.67	.15
			d	.05	44.8	-.49	-.65	.10
	Kingston	RI	a	1.57	38.8	-.53	-.71	.32
			b	.08	67.5*	-.49	-.67	.24
			c	.25	45.6	-.54	-.73	.35*
			d	.60	84.4*	-.51	-.68	.20
	Brandon	VT	a	1.63	64.5*	-.53	-.69	.18
			b	1.78	55.8	-.47	-.66	.20
			c	.10	28.7	-.50	-.68	.21
			d	1.18	29.5	-.46	-.61	.03
Piedmont	Warm Springs	GA	a	1.14	44.2	-.54	-.69	.20
			b	.14	42.0	-.50	-.65	.13
			c	.09	44.1	-.54	-.70	.24
			d	.78	46.0	-.53	-.69	.19
	Paterson	NJ	a	.55	66.8*	-.53	-.70	.73*
			b	.86	68.9*	-.46	-.62	.02
			c	1.56	33.8	-.49	-.66	.15
			d	1.03	41.5	-.48	-.64	.09

Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Piedmont	Washington West	DC	a	.02	60.1	-.46	-.63	.09
			b	.19	44.1	-.47	-.64	-.13*
			c	.83	50.3	-.51	-.67	.19
			d	.87	79.1*	-.47	-.64	.12
Blue Ridge	Mount Mitchell	NC	a	.10	23.2	-.52	-.69	.23
			b	.98	39.9	-.49	-.66	.17
			c	1.08	45.9	-.49	-.65	.11
			d	.35	50.3	-.52	-.69	.20
	Strasburg	VA	a	1.07	39.3	-.51	-.67	.16
			b	.90	63.3*	-.51	-.67	.14
			c	.41	48.2	-.50	-.68	.22
			d	.33	31.5	-.48	-.64	.13
	Sherando	VA	a	.73	43.3	-.51	-.67	.16
			b	.72	54.2	-.49	-.63	.06
			c	1.30	45.8	-.49	-.65	.16
			d	.40	76.3*	-.49	-.66	.13
Ozark Plateaus	Ironton	MO	a	1.14	58.8	-.51	-.66	.15
			b	.56	46.4	-.54	-.70	.24
			c	.13	47.5	-.50	-.67	.18
			d	.26	58.6	-.45	-.64	.16
	Saint Paul	AR	a	.05	35.6	-.48	-.64	.08
			b	.41	47.7	-.53	-.70	.26
			c	.79	80.3*	-.54	-.71	.25
			d	.08	60.7	-.54	-.72	.29
	Fidelity	MO	a	.50	58.8	-.60	-.75	.36*
			b	1.80	36.0	-.52	-.72	.33
			c	1.32	100.7*	-.49	-.64	.08
			d	.16	31.7	-.51	-.67	.18
Ouachita Mtns.	Horseshoe Mtn.	AR	a	.68	69.3*	-.52	-.69	.26
			b	.56	82.4*	-.49	-.64	.08
			c	1.16	68.4*	-.59	-.72	.24
			d	.47	61.2	-.57	-.73	.29
	Mena	AR	a	1.46	41.3	-.49	-.65	.10
			b	1.53	44.5	-.49	-.66	.15
			c	.53	30.3	-.50	-.67	.13
			d	.65	25.4	-.47	-.64	.13

Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Ouachita Mtns.	Lavaca	AR	a	.49	86.4*	-.62	-.78	.43*
			b	1.02	39.6	-.51	-.67	.18
			c	1.02	37.3	-.45	-.64	.14
			d	1.06	81.0*	-.50	-.66	.17
Valley and Ridge	Norris	TN	a	.08	34.3	-.51	-.65	.14
			b	.79	51.4	-.56	-.73	.32
			c	.25	58.0	-.46	-.60	-.01*
			d	.08	54.6	-.49	-.65	.10
	Alexandria	PA	a	.87	53.1	-.50	-.67	.18
			b	.61	23.5	-.51	-.66	.18
			c	.60	41.8	-.47	-.65	.14
			d	.10	70.3*	-.42	-.57	-.06*
	Saugerties	NY	a	.14	42.9	-.44	-.60	.01
			b	.07	41.3	-.47	-.63	.08
			c	1.50	83.3*	-.47	-.63	.04
			d	.47	45.8	-.48	-.68	.09
Appalachian Plateaus	Ithaca West	NY	a	2.77	61.4	-.41	-.58	0.0*
			b	2.78	35.2	-.51	-.69	.24
			c	1.54	62.6	-.55	-.71	.23
			d	3.53	38.2	-.50	-.69	.26
	Fayetteville	WV	a	.31	73.6*	-.47	-.64	.15
			b	.00	75.1*	-.47	-.65	.17
			c	.21	63.0*	-.53	-.72	.32
			d	.25	82.4*	-.46	-.64	.12
	Whitwell	TN	a	.06	71.7*	-.45	-.64	.15
			b	.45	54.8	-.48	-.64	.08
			c	1.50	57.6	-.47	-.66	.19
			d	.40	40.7	-.50	-.66	.14

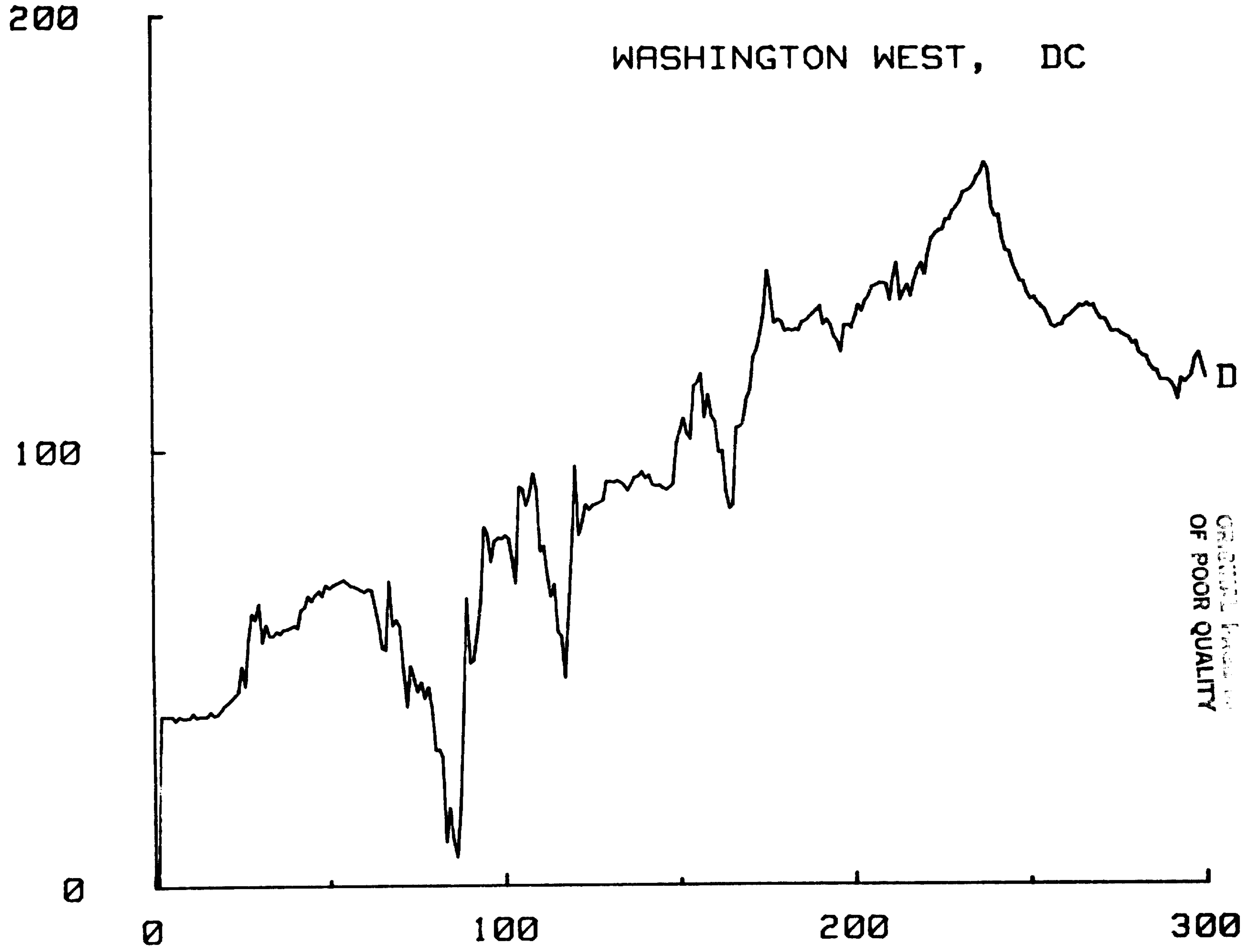


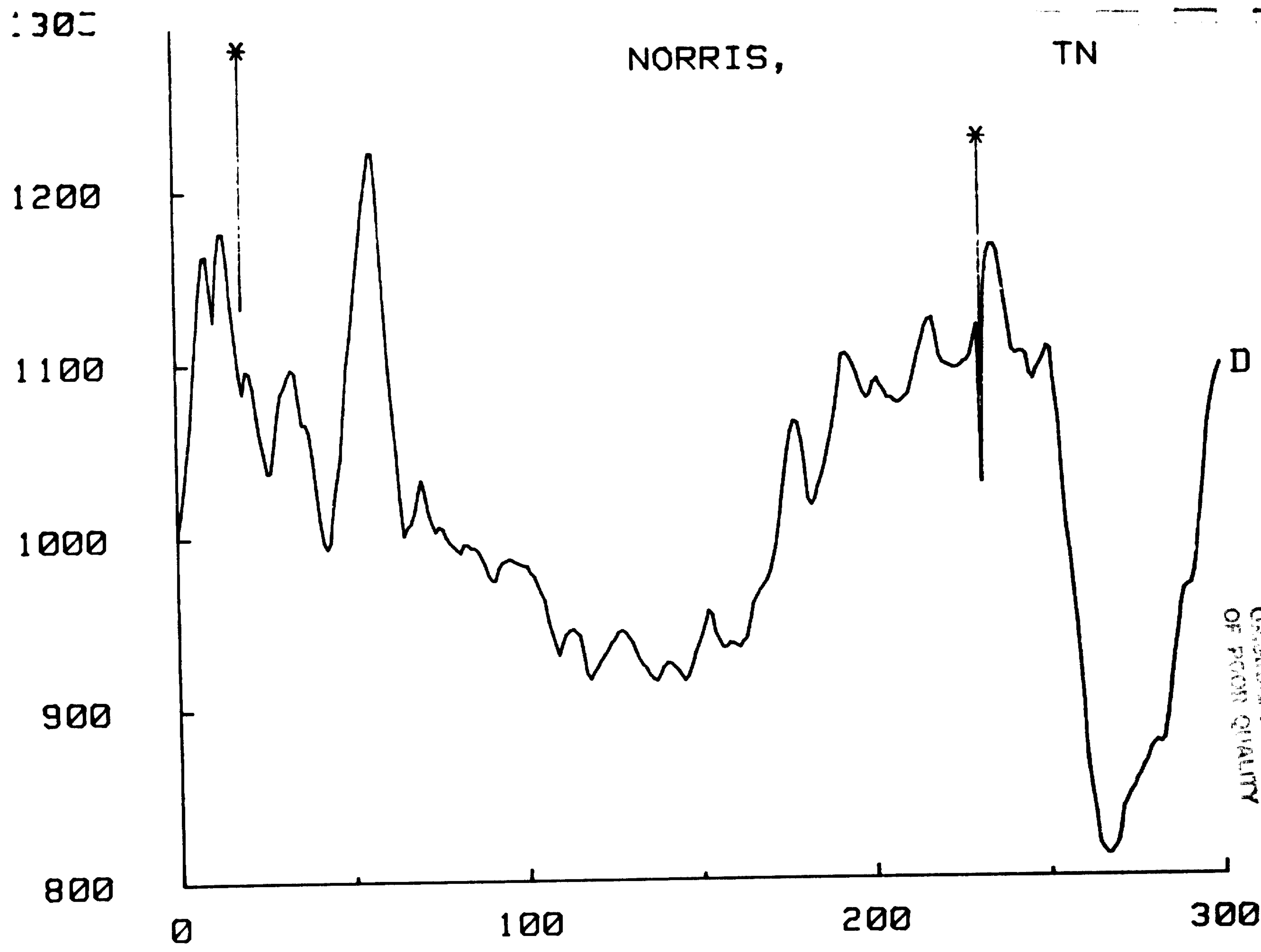
Figure 12. Typical plot of residuals from the best fit ARIMA (2,1,0) model.

within certain limits, as discussed previously, any deviations from expectation were taken as an indication of possible errors in the data. This was found to be the case for 18 traverses. Detection of the actual error was more difficult in these cases since the obvious ones had much earlier been detected. A typical error is illustrated in figure 13. Most of those errors were found to be typographical in nature. A special program was set up to examine traverses to detect errors such as that in figure 13. This program is listed in the Appendix. Where errors such as that in figure 13 could not be found, suspicious traverses were checked point by point against the original data sheets. If an error still was not found the original maps were again referred to. Other possible sources of error will be mentioned in Section VII.

Once the fits and estimates were accepted as reasonable the values of ϕ_1 and ϕ_2 were plotted for each quadrangle (Appendix). This gives an idea of the uniformity of values within the quadrangle and is another means of detecting inaccurate estimates. When one value deviated greatly from the other three, even though it still fell within the acceptable area, the original traverses were again checked for possible erroneous values. On the triangular plots of ϕ_1 versus ϕ_2 are also listed a number of summary statistics from the analyses for that quadrangle as well as a summary of the climatic data for the nearest station and information about the quadrangle map itself.

Once the data had been thus thoroughly checked and subject to scrutiny they were subject to analysis to test the concepts presented in the introduction. A separate Analysis of Variance was done for each parameter (ϕ_1 and ϕ_2). The design was a nested one with quads nested within province. Traverses, with four levels, were considered crossed

Figure 13. Typical errors within a traverse (Norris-D). Asterisk shows error. Error on right is a large typographical one which was easily detected early. Error in left only showed up after parameters were estimated and proved to be suspicious.



NORRIS, TN
1300
1200
1100
1000
900
800
0
100
200
300
*
*
D

with province in order to consider the possibility that there is a systematic tendency for say slopes on north-south oriented traverses to contain a different process mix than other slopes. Following the analysis of variance a multiple comparison test was performed to determine which levels of the significant factors could be considered significantly distinct.

IV. RESULTS

This chapter will be divided into two parts in the first the appropriateness of the original assumptions about process representation by means of an ARIMA (2,1,0) model will be evaluated through a number of tests. Results presented in that part appear to fully substantiate the chosen model. Part two therefore uses the estimated parameters of that model to examine the question of significant variation in process rates from quadrangle to quadrangle within a physiographic province and from province to province. In this part the results of the analysis of variance and multiple comparison tests are presented.

Fortunately, there are a large number of tests available to check the appropriateness of the hypothesized process form association. They may be conveniently divided into two groups. The first addresses the question: How likely is the ARIMA (2,1,0) model to be correct compared to other alternatives? The second group examines the goodness of fit of the actual estimated parameters since they are further constrained by geomorphic considerations.

Comparison of the ARIMA (2,1,0) to other alternatives can be accomplished satisfactorily by examining the ACF's and PACF's of the elevation traverses and their first differences (i.e. slopes). An alternative model would still be a member of the ARIMA (p,d,q) family. Thus, they must be recognized by showing a different value of p, d or q or some combination of these three. Each of these can be detected using the ACF's and PACF's.

It has been assumed that essentially all traverses under study will show the same model (although the parameter values may differ). An alternative that ought to be considered is that there is no systematic

structure to elevation traverses; any observed structure may simply be coincidental; each area could show a different model and the model (or models) may carry absolutely no implication about the processes. It should also be remembered that the processes under consideration do not comprise the entire set of geomorphic processes. Certainly mass wasting influences landforms, especially in areas of high relief. Thus, some departures from the model can be expected, if such areas are included in the study.

Of the three parameters to be considered, q, can be disposed of most readily. If q is non-zero the PACF will show a sinusoidal pattern or a damped exponential form or some mixture of the two. This would be the case if q was 1 or 2; more complicated models ($q \geq 3$) clearly do not apply to these data. Whether the $q \neq 0$ pattern shows up in the PACF of the original series or in the dth difference series (slopes, changes in slope, etc.) depends upon the correct value of d in the model. As will be shown, it is highly likely that d is 1 (as also predicted by theory). Thus, we can expect that any $q \neq 0$ pattern will show up in the PACF of the first differences (i.e. the slope series). These were examined with especial interest in the occurrence of exponential or damped sinusoidal patterns (Table VII). As can be seen from inspection of the table, such patterns are "found" in only eight of the 96 traverses. In each case these "patterns" are quite problematical; whether they actually exist is open to question. A conservative approach was taken in that anything that was anywhere close to the form of interest was accepted as being real. Note that none of these so-called patterns actually extend beyond the significance limits. The most convincing example is shown in figure 14. It is also important to note that comparable patterns were found in the

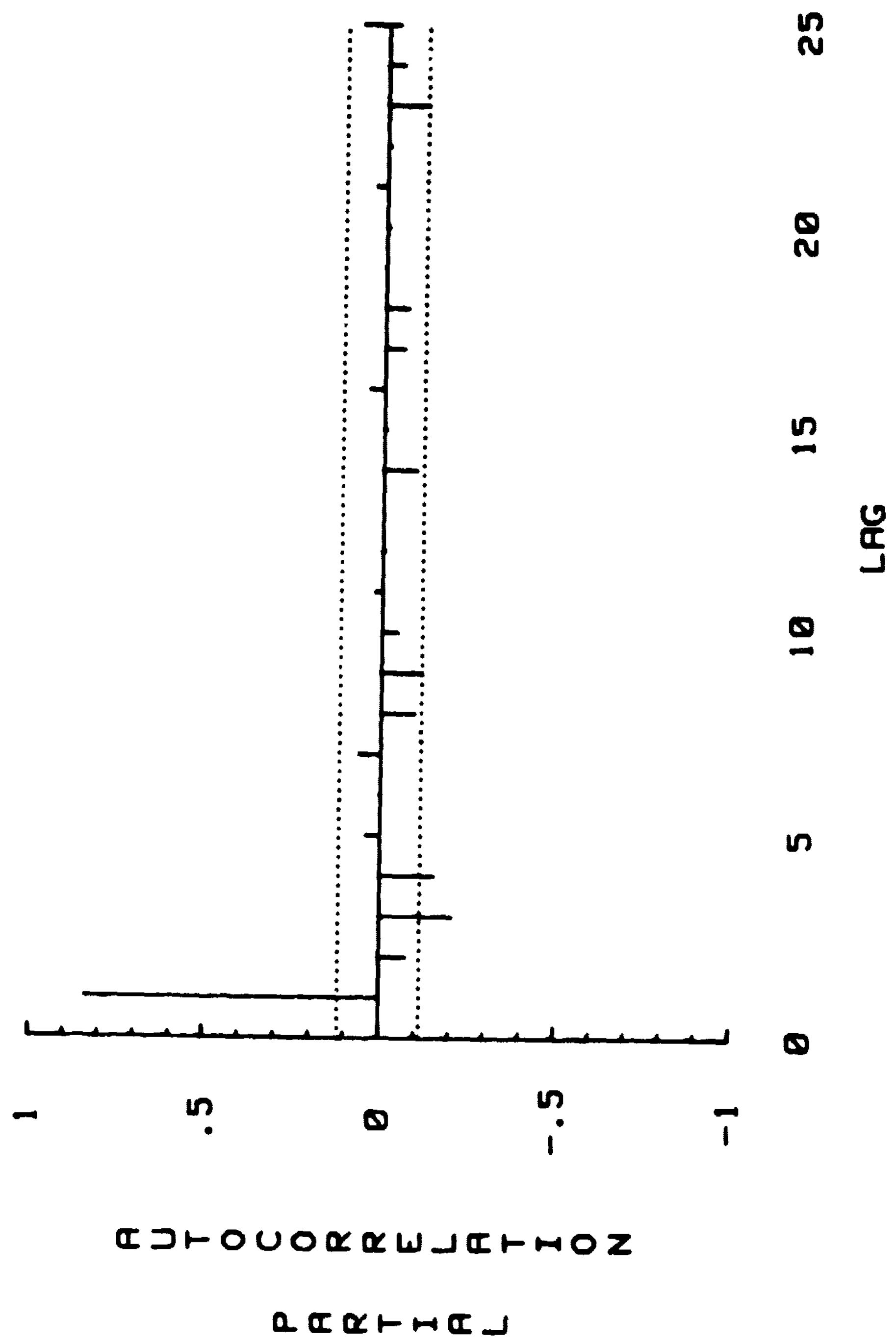
Table VIL Occurrence of significant lags and suspected patterns in the PACF of the slopes. In the first column for each traverse the numbers indicate which lags (out of the first ten) have significant values. In the pattern column Y indicates a simple pattern may exist; see footnote for a description, N indicates there is no simple pattern.

	TRAVERSE	a		b		c		d	
Province	Quadrangle	sign. lags	pattern	sign. lags	pattern	sign. lags	pattern	sign. lags	pattern
Interior Lowlands	Mammoth Cave	1	N	1	N	1	N	1	N
	Hillsboro	1	N	1	N	1	N	1	N
	Rover	1	N	1	N	1	N	1	N
New England	Ayer	1	N	1	Y[a]	1,2	Y[b]	1	N
	Kingston	1	N	1	N	1	N	1	N
	Brandon	1	N	1	N	1	N	1	N
Piedmont	Warm Springs	1,2	Y[c]	1	N	1	N	1	N
	Paterson	1	N	1	N	1	N	1	N
	Washington West	1	N	1	N	1	Y[d]	1,2	N
Blue Ridge	Mount Mitchell	1	N	1	N	1	N	1	N
	Strasburg	1	N	1	N	1	N	1	N
	Sherando	1	N	1	N	1	N	1,5	N
Ozark Plateaus	Ironton	1	N	1	N	1	N	1	N
	Saint Paul	1	N	1	N	1	Y[e]	1	N
	Fidelity	1	N	1	N	1	Y[e]	1	N
Ouachita Mtns.	Horseshoe Mtn.	1	N	1	N	1	Y[e]	1	N
	Mena	1	N	1	N	1	N	1	N
	Lavaco	1,2	N	1,2	N	1	N	1	N
Valley and Ridge	Norris	1	N	1	N	1	N	1	N
	Alexandria	1	N	1	N	1	N	1	N
	Saugerties	1,2	N	1	N	1,2	N	1	N
Appalachian Plateaus	Ithaca West	1	N	1,2	N	1,2	N	1	N
	Fayetteville	1,2	Y[e]	1	N	1	N	1	N
	Whitwell	1	N	1	N	1	N	1	N

a. negative seasonal at four lags
b. exponential decay (positive)
c. exponential decay from lag 2 (negative)
d. all values after first lag are negative
e. very weak sinusoidol

ORIGINAL PAGE IS OF POOR QUALITY

Figure 14. The most obvious example of a sinusoidal pattern in the PACF which could suggest a need for an MA term in the model. As can be seen the "pattern" is questionable and barely extends beyond the significance limits (dotted).


PARTIAL
AUTOCORRELATION
1
.5
0
-.5
-1
LAG
0
5
10
15
20
25

PACF's of at least five other slope series but disappeared after known data errors were corrected. Thus, it is quite possible that these patterns may simply be an indication that further (necessarily minor) errors remain in these series. At any rate, the information displayed in table VII is (in at least 92% of the cases) precisely what would be expected if the ARIMA (2,1,0) model is correct. It is the authors opinion that no reasonable interpretation of this information would allow general rejection of the ARIMA (2,1,0) model. Furthermore, it would appear on the basis of this information that the same single model applies nearly universally to all of the study areas.

Determination of the correct value of d is both a critical test of the model and conveys significant geomorphic meaning. To claim that d = 1 implies that the correct phenomena to study is the behavior of, and influences upon, slopes rather than, for example, raw elevations themselves. It also implies that elevations are a non-stationary phenomenon which has also been claimed by Mandelbrot (1977). Examination of d will be divided into four parts. First, for each series we will consider if any differencing is needed at all (Ho: d = 0; Ha: d > 0). It will be shown that the null hypothesis can be rejected universally in favor of the alternative; some kind of differencing should be done. Next, we will consider if perhaps a higher order difference is not preferable (Ho: d = 1; Ha: d > 1). It will be shown that in a large number of cases this would definitely be overdoing it. That is, d is <u>at most</u> equal to one. Third, we will test whether d = 1 is <u>sufficient</u>. The idea is that even if d = 2 could be accepted in some cases, it is also the case that d = 1 would yield an equally acceptable (or more acceptable) model but would be <u>more parsimonious</u> and thus preferable. Finally, we will consider the question of the

universality of the d = 1 part of the model.

Three interrelated bits of data are available that show that use of the original data (as opposed to some appropriate difference) is unacceptable. The very high values of ρ_1 (none less than 0.97) in the ACF of the original series (Table VIII) imply that without an explicit difference (i.e. with d = 0) the series would universally require a model which had a ϕ_1 parameter nearly or exactly equal to 1.0. This is essentially equal to a model with d = 1, it implies a non-stationary model and would make estimates of other parameters unreliable. Another strong indication of non-stationarity is provided by the very slow rate at which the ACF decays from this large initial value. Most of the series show ACF's that remain positive throughout the entire range of lags computed (either 25 or 48). Of those that do reach zero, the quickest "decay" is in 23 lags (Table VIII) although the decay pattern remains strong throughout and no "noisy" random fluctuations such as would be expected in a stationary series are observed. In general, a stationary model would be expected to display such "noisy" behavior by the 10th or, at the very most, by the 20th lag. Thus, the rate of decay of the series give a universal indication that differencing is needed. Finally, the extremely large values of χ^2 obtained from the portmanteau test of the ACF of the original series (all exceed 1000 although the [illegible]% cut-off is 65.17) provide strong indication that the original series are not remotely near being white noise (p = d = q = 0) and that they are almost certainly non-stationary. Thus, the combination of the three lines of evidence as well as geomorphic reasoning provide a clear indication that the original series (elevations) are not appropriate for analysis and that some value of d greater than zero will be required to produce such a series.

Table VIII. Data from autocorrelation functions of original series and first and second differences relevant to the identification of the appropriate value of d in the ARIMA (p,d,q) model.

Column Headings

4	Autocorrelation of original series at lag one.
5	Lag at which first negative value is found. An N means that no negative values were computed.
6	Number of lags computed. This value is also the number of degrees of freedom in the portmanteau tests.
7	Value of x^2 in portmanteau test of ACF of the original series.
8	Value of x^2 in portmanteau test of the first difference.
9	Ratio of x^2 from original series to that of first difference. Less than a sixfold reduction is indicated by an asterisk (*).
10	Value of x^2 in portmanteau test of the second difference. Significant values (exceeding 65.17) are indicated by asterisks (*).
11	Significant negative values at lag one of the second difference series. A "Y" means significant, and "N" not significant.

Province	Quadrangle		4	5	6	7	8	9	10	11
Interior Low	Mammoth Cave	a	.99	N	25	3470.1	424.91	8.2		N
		b	.99	N	25	3430.8	363.24	9.4		N
		c	.98	N	25	3399.1	251.15	13.5		N
		d	.97	24	25	1761.5	227.93	7.7		N
	Hillsboro	a	.98	N	48	2687.6	276.89	9.7	74*	N
		b	.98	47	48	2921.3	280.74	10.4	66*	N
		c	.98	N	48	3187.7	280.47	11.4	63	N
		d	.97	38	48	2881.8	177.78	16.2	89*	Y
	Rover	a	.98	46	48	3440.0	269.44	12.8	55	N
		b	.99	45	48	3467.2	380.16	9.1	51	N
		c	.99	N	48	4520.7	634.09	7.1	56	Y
		d	.99	N	48	4474.0	464.23	9.6	76*	Y
New England	Ayer	a	.99	41	48	3597.2	182.75	19.7	118*	Y
		b	.99	N	48	4756.8	439.40	10.8	74*	N
		c	.98	N	48	3793.7	1452.60	2.6*	70*	Y
		d	.99	N	48	3747.4	408.12	9.2	62	Y
	Kingston	a	.97	N	25	2699.1	249.51	10.8		N
		b	.99	N	25	4856.5	107.12	45.3		Y
		c	.99	48	48	4441.8	267.56	16.6	126*	N
		d	.97	24	25	2026.3	157.44	12.9		N
	Brandon	a	.99	N	48	6351.5	520.32	12.2	75*	Y
		b	.99	N	48	6642.6	600.13	11.1	98*	Y
		c	.97	N	48	3432.0	413.16	8.3	57	N
		d	.99	N	48	6041.9	536.13	11.3	50	Y
Piedmont	Warm Springs	a	.99	N	25	5793.4	264.35	21.9		N
		b	.99	N	25	2274.0	315.18	7.2		N
		c	.98	N	25	3073.0	202.59	15.2		Y
		d	.98	N	25	3546.5	245.24	14.5		N
	Paterson	a	1.00	N	48	7694.2	552.33	13.9	86*	N
		b	.99	N	48	5196.8	422.66	12.3	89*	N
		c	.99	N	48	7599.7	215.15	35.3	62	Y
		d	1.00	N	48	9688.2	442.22	21.9	59	N
	Washington West	a	1.00	N	25	5655.8	179.11	31.6		Y
		b	.99	N	25	4422.4	241.08	18.3		N
		c	.98	N	25	3332.3	258.08	12.9		N
		d	.99	N	25	5446.7	253.33	21.5		N

Province	Quadrangle		4	5	6	7	8	9	10	11	
Blue Ridge	Mount	a	1.00	40	48	5037.8	799.38	6.3	35	Y	
	Mitchell	b	.99	N	25	4941.0	814.08	6.1		Y	
		c	.98	N	25	3193.0	294.50	10.8		N	
		d	1.00	N	48	6142.8	736.07	8.3	63	N	
	Strasburg	a	.99	N	48	6138.8	496.63	12.4	53	Y	
		b	.99	N	48	4980.4	324.31	15.4	72*	N	
		c	.99	37	48	4481.2	570.77	7.9	65	Y	
		d	1.00	N	48	7432.9	769.52	9.7	39	N	
	Sherando	a	1.00	N	48	6352.2	1186.50	5.4*	58	Y	
		b	1.00	N	48	7532.3	1095.30	6.9	59	N	
		c	1.00	N	48	8352.8	778.71	10.7	53	N	
		d	1.00	N	48	7631.2	1761.40	4.3*	92*	N	
		a									
Ozark	Ironton	a	.99	N	25	5351.7	485.84	11.0		Y	
Plateaus		b	.99	N	25	3803.6	579.91	6.6		N	
		c	.99	N	25	4580.4	820.61	5.6*		Y	
		d	1.00	N	25	5940.5	673.43	8.8		Y	
	Saint Paul	a	.98	N	25	3133.1	733.37	4.3*		N	
		b	.99	23	25	2594.7	801.44	3.2*		Y	
		c	.99	N	25	4685.8	307.40	14.9		N	
		d	1.00	N	25	4892.0	773.89	6.3		Y	
	Fidelity	a	.97	N	48	5002.4	269.88	18.6	25	Y	+ve
		b	.98	N	48	4981.5	208.48	23.9	57	Y	
		c	.99	N	48	8355.4	246.56	34.0	179*	Y	
		d	.98	N	48	5106.6	217.45	23.5	50	N	
Ouachita	Horseshoe	a	.99	N	25	4319.8	572.29	7.6		N	
Mtns.	Mtn.	b	.99	N	25	3674.0	601.18	6.1		N	
		c	.97	N	25	1628.0	604.93	2.7*		N	
		d	.97	N	25	2091.9	509.82			Y	
	Mena	a	.98	42	48	3696.8	292.33	12.7	55	N	
		b	.99	N	48	8132.6	400.73	20.3	53	N	
		c	.98	23	48	2324.0	186.67	12.5	59	Y	
		d	.98	40	48	3747.5	240.75	15.6	42	N	
	Lavaca	a	.99	N	48	6283.1	360.43	17.5	107*	N	
		b	.97	31	48	2276.1	704.68	3.2*	108*	Y	
		c	.97	N	48	3299.9	839.52	3.9*	69*	Y	
		d	.99	N	48	7443.2	628.06	11.9	92*	N	

Province	Quadrangle		4	5	6	7	8	9	10	11
Valley and Ridge	Norris	a	.99	N	48	3766.8	484.08	7.8	44	N
		b	.97	N	48	3878.7	499.03	7.8	52	N
		c	.98	N	48	4101.2	610.26	6.7	63	N
		d	.99	33	48	2904.4	204.22	14.2	70*	N
	Alexandria	a	.99	N	48	5413.5	345.46	15.7	76*	N
		b	.98	N	48	3041.4	258.10	11.8	36	N
		c	.99	N	48	4962.4	492.34	10.1	71*	N
		d	1.00	47	48	5092.4	492.49	10.3	102*	Y
	Saugerties	a	.99	N	25	3802.4	186.64	20.4		N
		b	1.00	N	25	5318.0	399.27	13.3		N
		c	.99	N	25	4199.9	297.78	14.1		N
		d	.99	N	25	4362.9	270.11	16.2		N
Appalachian Plateaus	Ithaca West	a	.99	N	48	7919.9	745.20	10.6	79*	N
		b	.99	N	48	6931.4	216.54	32.1	89*	N
		c	.98	N	48	5560.2	244.43	22.8	110*	N
		d	.99	N	48	8312.0	767.13	10.8	62	N
	Fayetteville	a	1.00	N	48	5818.8	472.14	12.3	111	Y
		b	1.00	N	25	3178.9	971.26	3.3*		Y
		c	1.00	N	25	3669.6	596.22	6.2		Y
		d	.99	38	48	4395.4	867.14	5.1*		Y
	Whitwell	a	1.00	N	48	7715.3	2534.90	3.0*	89*	Y
		b	.98	N	48	4121.9	257.82	16.0	104*	Y
		c	.99	N	48	6785.1	725.25	9.4	74*	N
		d	1.00	N	48	7353.3	1054.50	7.0	54	Y

That some differencing is always required is now quite clear. Is it first order or higher? The possibility that a higher order difference would be preferable is to be considered next. This possibility is tested by comparing the results of the portmanteau tests of first and second order differences, by examining the sufficiency of a straight second order difference model, and by considering the necessity of a second order difference.

Table VIII shows that a first order difference significantly reduces the values of χ^2 in the portmanteau tests. Whereas the value is always above 1000 for the undifferenced series it is rarely above 1000 when $d = 1$ (only 6% of the cases) and is usually in the range 100 to 600. These latter values are reasonable if the full model contains ϕ_1 parameters in the range 0.5 to 1.0 as anticipated in the theoretical model (recall chapter II, "Theory," page). The extent that the first order difference reduces the χ^2 value is also listed in Table VIII. As can be seen, the typical reduction is about an order of magnitude, the smallest is by a factor of 2.6; only 13% of the reductions are less than a factor of 6. In contrast to this, the reduction in going from $d = 1$ to $d = 2$ is not nearly as drastic. The reduction is rarely as great as a factor of 6. If the first difference series were non-stationary we could expect at least as large a reduction, if not more. As will be shown next in the discussion of the $p = 2$ terms, the ACF of the first difference shows consistent evidence of stationarity. Thus, it appears quite definite that all of the non-stationarity is removed by a first difference. The only structure remaining after the first difference, and producing significant values of χ^2 in the portmanteau test, is that due to stationary terms (in particular ϕ's, such as ϕ_1 and ϕ_2 as hypothesized in the theoretical model). Thus,

the first order difference model is quite definitely sufficient to ensure stationarity (providing $p > 0$).

In contrast it is clear from Table VIII that a simple second order model (i.e. $p = q = 0$, $d = 2$) is not sufficient. The portmanteau test shows that white noise is not acheived in at least 48% of the traverses. Thus, if it were true that $d = 2$ it would for at least these traverses be necessary to add additional terms (probably ϕ's). Thus, the models would be at least as complicated as the one theorized. Additionally, the $d = 2$ concept would carry with it the implication that models differ from site to site and no general geomorphic process/form model can be discerned. Not only is the $d = 2$ model not sufficient, it appears that it is not necessary in that it provides more model than is appropriate; it overdoes the job. This can be seen from the values of ρ_1 in the ACF of the second differences. A large proportion (39%) of the series have significant negative values at lag 1; a large number of other series show large but not significant negative values. Such a pattern is usually taken as *prima facie* evidence that the series has been over-differenced. The resulting model would require $\phi_1 < 0$ and this essentially is only a correction for taking $d = 2$ rather than $d = 1$. Although this particular evidence of overdifferencing is not universal, it does occur in at least one traverse in all quadrangles but four. Thus, it is again clear that a $d = 2$ idea carries with it the implication that no one model is sufficient and that these procedures cannot produce geomorphic process/form understanding. Although this could at best imply that two models are sufficient, study of the remaining four quadrangles provide strong evidence that a great variety of different models would be required. Table IX lists the different significant lags in these traverses when $d = 2$. Addition of one parameter

Table IX. Significant lags found in the four quadrangles for which the second difference model is acceptable for all four traverses.

quadrangles		significant lags
Mammoth Caves	a	4,6
	b	2,3
	c	2
	d	3,4,7
Saugerties	a	2,5
	b	2,4,7
	c	2,4,6,7,10
	d	2,5
Norris	a	6
	b	3,9
	c	2,6,9
	d	4,10
Ithaca West	a	2
	b	2,3
	c	2,3,4
	d	2,3

certainly cannot produce such a variety of patterns. Thus, setting $d = 2$ could only lead to obfuscation of the relations which exist between adjacent slopes.

It appears from the above evidence that a first difference is certainly necessary and is quite likely sufficient to model the autocorrelation of the traverses when combined with some ϕ terms. It is clear that all traverses universally require at least $d = 1$ so that choice of this model is satisfying in its general applicability. It remains to be seen whether this universality can be maintained in the choice of p.

Next, we will consider the evidence concerning the appropriateness of the $p = 2$ portion of the model. As shown in chapter II any of four patterns in the ACF could be expected if it is true. Geomorphic considerations, however, limit the expected parameter values to the area shown in figure 7, therefore, only patterns of types A and B (Figure 2) should be found. Thus, the ACF should appear to be mixed exponentials or a damped sine wave. Presumably near the boundary of the two regions a combination of the two could occur. Other patterns would be an indication that the $p = 2$ idea is not correct. At this point it should be recalled that it is reasonable to consider $p = 1$ to be a legitimate subset of the general model. This is so if $\phi_2 = 0$ which could occur if the landform is not significantly shaped by creep. If $p = 1$, the ACF will look like a pure exponential decay. The ACF's were examined to determine what sort of pattern could be observed. As can be seen in Table X <u>all</u> traverses show either an exponential decay, a damped sinusoidal form or a combination of the two. Five of the 96 traverses show a very slow decay which could be interpreted as a possible need for futher differencing. In no case is the decay as slow as was seen in the original series. As will be shown

Table X. Patterns observed in the autocorrelation function of the first differences of the traverses.

Province	Quad	Traverse Patterns			
		a	b	c	d
Piedmont	1	S	S	S	S
	2	E with weak S	E with weak S	E with S	mixed E and S
	3	mixed E and S	mixed E and S	mixed S	S
Blue Ridge	1	E	E	S	S
	2	S	S	mixed E and S	E with slight S
	3	E with very slight S	E with slight S	E with slight S	very slow decay mixed E and S
Valley and Ridge	1	S	S	mixed E and S	S
	2	E possible S	E	S	E possible S
	3	S	mixed E and S	S	S
Appalachian Plateaus	1	S with slow decay	S	S	very slow decay S
	2	mixed E and S	very slow decay S	mixed E and S	mixed E and S
	3	very slow decay E with possible S	strong E with slight S	strong E with slight S	strong E with slight S
Interior Low Plateaus	1	S	mixed E and S	S	S
	2	strong S	strong S	strong S	S
	3	S	S	S	E with slight S
New Englend	1	S	S with slight E	S	S
	2	mixed E and S	S	S	S
	3	S or mixed E and S	mixed E and S	mixed E and S	possible E or E with MA(2) term
Ozark Plateaus	1	S	mixed E and S	E	mixed E and S
	2	mixed S and E	E with slight S	S	S with slight E
	3	S	mixed E and S	mixed E and S	S
Ouachita Mountains	1	strong S	strong S	strong S	strong S
	2	S	S	S	S
	3	S	E with slight S	E with very slight S	S

E = exponential decay
S = sinusoidal form

later, in all cases the estimated parameter, ϕ_1, is below 1.0 and in only one of these five cases does the 95% confidence limit about the estimated value even include 1.0. This is strong evidence that further differencing is not required. Only one traverse (Brandon Vermont, d) shows a strong departure from the basic exponential/sinusoidal pattern. In this traverse a mixed model (i.e. both $p \neq 0$ and $q \neq 0$) is suggested. However, the PACF does not support this notion since it does not display the necessary exponential/sinusoidal pattern. Thus, it appears that the ARIMA (2,1,0) model although a poor fit is apparently the best one available even in this case. Interestingly, as Table V shows, this traverse did produce an unusually low value for $\hat{\phi}_1$ (0.39) whereas almost all other estimates exceed 0.50.

It is concluded on the basis of the patterns observed in the ACF that a value of $p = 2$ is the most reasonable one for the traverses. For some it could be found that $\hat{\phi}_2 = 0$ and so $p = 1$ is an adequate model in that case. Still this can be considered a subset of the $p = 2$ model. There does not seem to be a systematic way of determining which, if any, traverses have $p = 1$ short of actually estimating ϕ_1 and ϕ_2. It is a safe procedure to assume $p = 2$ since overfitting will show up the needed simplification. In general, it would appear to be a valid and obviously parsimonious step to assume at this point that $p = 2$ is a universally applicable part of the model.

At this stage it is apparently appropriate to assume that all three parts (p, d and q) of the ARIMA model are as theorized. We, therefore, next actually "fit" an ARIMA (2,1,0) model to each traverse. That is, the values of ϕ_1 and ϕ_2 are estimated from the data using least squares procedures. Such procedures are iterative and thus require starting values.

Preliminary estimates were obtained from ρ_1 and ρ_2 using the formula given previously (page 17). These values are listed in Table IV. The more reliable final estimates are given in Table V. Comparison of these two tables shows that in most cases the preliminary and final estimates are quite close. However, there are enough instances of large changes that reliance should be placed on only the final estimates (Figure 11). An additional advantage to obtaining the final estimates is that it allows confidence limits to be estimated. This was done and the upper and lower 95% confidence limits are also given in Table V. These confidence limits provide an additional, and very sensitive, test of the appropriateness of the postulated ARIMA (2,1,0) model. Having such confidence limits we can determine if it is possible to reject the postulated model (as a null hypothesis) which would have $0 < \phi_1 < 1$ and $-1 < \phi_2 < 0$. As can be seen from Table V all 96 estimated values of ϕ_1 fall within the postulated range. This should be considered in light of the fact that the possible range of invertible values is $-2 < \phi_1 < 2$. More interestingly, only four traverses yield values of $\hat{\phi}_1$ which are lower than 0.50. This provides a hint that the process rates are even more tightly constrained than suggested in the original model. Further support for this is given by considering the overall mean which is 0.741 with a standard deviation of 0.119. If all areas studied are being modified by this process mix at the same rate, subject only to normally distributed random fluctuations (an hypothesis to be tested shortly), then there is a 95% probability that the true rate is in the range $0.717 < \phi_1 < 0.765$. That is, within the areas studied it appears that these processes (slope wash and creep combined) are changing slope form at about three-quarters of the maximum possible rate. Furthermore, it is highly unlikely (less than 5% chance) to find rates lower than

0.50 or greater than 0.98. The highest value actually observed was 0.96 (Lavaca, a). The near coincidence of these two upper limits imply that it is highly unlikely to observe non-stationary slope series; a first difference of elevations is adequate and correct, a second difference is unnecessary and supercilious. An additional support for this statement is given by the individual upper 95% confidence limits for the estimates of ϕ_1. In only nine cases does the upper limit include 1.0 (the largest value is 1.07). Even a value of 1.0 is stationary unless ϕ_2 were greater than or equal to zero. In no case does the lower 95% confidence limit include zero. Thus, it is clear that a ϕ_1 parameter is required in the model.

Although the hypothesized upper limit for ϕ_2 is 0.0 a fair number of traverses (31) yield values greater than zero. However, in 22 of these the value is very close to zero and the lower 95% confidence limit does include zero. Thus, taking $0 \geq \phi_2$ as the null hypothesis only nine (of 96) traverses allow rejection at the 95% confidence level (about 5 rejections are to be expected at this confidence level). The mean value of all 96 traverses is -0.05 with a standard deviation of 0.126. At the 95% level of confidence the true population mean must fall in the range $-0.076 < \phi_2 < -0.025$ if these <u>are</u> all samples from a single population subject only to random fluctuations. Thus, there is no reason to suspect that the true expected value varies from the hypothesized range of possible values. In each of the eight provinces but one (Blue Ridge) the mean value (of 12 traverses) is negative. For the Blue Ridge the value is so small (0.011) that it is not significantly different from zero. This would seem to imply that within this province (or at least in the three quadrangles studied) creep was not a significant factor in shaping the landform.

The presence of some positive values of ϕ_2 is not necessarily incompatible with the hypothesized model. If the true value of ϕ_2 for a traverse is zero and the estimated values are subject to some random (normally distributed) error not related to the variability in process rate itself, then a positive value is possible. A natural error source in these estimates is that resulting from the data collection process itself. A considerable number of errors were detected and corrected during the study; it is quite conceivable that additional errors remain; although they can be expected to be small. In some cases errors were not detected until estimates of ϕ_2 had already been made. When such errors were corrected and $\hat{\phi}_2$ recomputed it was always found that the new value was lower, either negative or at least considerably closer to zero. Table XI lists these corrections. Such changes are a strong suggestion that sampling errors, even minor errors on a single point out of 301, tend to introduce a positive bias in the estimate of ϕ_2. Because ϕ_1 and ϕ_2 are negatively correlated such bias could tend to produce a bias toward smaller values for $\hat{\phi}_1$. Such effects were also noticed in the corrected series mentioned. These effects may also be present in certain traverses. An example of such a phenomenon may be given by the Fidelity-c traverse ($\hat{\phi}_1 = 0.38$, $\hat{\phi}_2 = 0.13$); although no error has been detected, the values are anomalous and suspicious.

The correctness of the model is demonstrated quite conclusively by the upper 95% confidence limit of ϕ_2. Of the 96 traverses, 27 have an upper limit which is negative, indicating that any alternative model is highly unlikely for at least this proportion of the traverses. Thus, the model is sufficient to explain at least 90% of the observations, and is uniquely capable of explaining 28% of the observations.

Table XI. Effects of errors in traverse elevations upon the final estimates of ϕ_1 and ϕ_2. Parameters estimated after correction of data are also listed for comparison.

Quadrangle Name	Traverse	With errors ϕ_1	With errors ϕ_2	After correction ϕ_1	After correction ϕ_2
Ayer	C	.11	.51	.77	.089
Brandon	D	.39	-.080	.67	.059
Fayetteville	A	.50	.25	.51	.25
Fayetteville	D	.67	.062	.70	.033
Hillsboro	D	.57	-.14	.57	-.14
Lavaca	B	.52	.29	.53	.28
Mena	A	.13	.22	.76	-.10
Mount Mitchell	A	.50	.26	.75	.075
Mount Mitchell	D	.52	.28	.81	.017
Rover	A	.38	.14	.73	-.11
Sherando	C	.39	.39	.81	.048
Strasburg	A	.45	.29	.75	.044

The preceding analysis shows that when an ARIMA (2,1,0) model is assumed the resulting estimates of ϕ_1 and ϕ_2 fall within the range expected on the bas... of ... omorphic arguments. It remains to be seen whether this model with those specific parameter values will actually produce a fit to the observed series that is statistically acceptable. The goodness of fit of the estimated model can be evaluated by means of seven tests; all are based upon the assumption that if the fit is correct the residual series will not differ from white noise. This residual series is obtained by subtracting values predicted using the model from the actual observed series as explained earlier (Chapter II, p. 9). The results of these tests are described next.

If the residual series is as expected the mean of the series should be zero. A t-test for significant departure from zero is the first test (Table XII). As can be seen the null hypothesis (true mean is zero) is rejected in only two of the 96 cases (whereas about 5 could be expected at the 95% confidence level used). Thus, this test provides no evidence to allow rejection of the fit of the model.

The second test, the portmanteau test, is a check for the tendency for significant autocorrelations to occur in the ACF of the residuals. If the residuals are white noise the values should not significantly differ from zero at any lags. The portmanteau test is based upon the Chi-squared statistic and also is reported in Table XII. In general, the traverses pass this test, however there are 27 traverses which display χ^2 values exceeding the 95% cut-off. That this is not a statistical fluke is suggested by the fact that 10 of the traverses display values exceeding the 99.5% cut-off. Thus, there is some indication on the basis of this

Table XII. Results of first five tests of residuals from the ARIMA (2,1,0) model. Tests are explained in the text. An asterisk indicates the value exceeds the 95% confidence limit.

Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Interior Low	Mammoth Cave	KY	a	.07	57.3	-.56	-.71	.24
			b	.26	43.8	-.49	-.67	.22
			c	1.10	35.8	-.50	-.65	.11
			d	.01	52.9	-.52	-.69	.23
	Hillsboro	KY	a	.02	58.1	-.57	-.73	.28
			b	.40	72.8*	-.53	-.71	.27
			c	.16	49.3	-.52	-.68	.19
			d	.35	72.3*	-.57	-.75	.36*
	Rover	TN	a	.13	40.4	-.55	-.73	.35*
			b	.76	40.6	-.52	-.67	.15
			c	.44	39.1	-.50	-.67	.18
			d	.01	55.1	-.50	-.65	.13
New England	Ayer	MA	a	.11	68.5*	-.50	-.65	.07
			b	.25	67.3*	-.51	-.69	.24
			c	.27	67.5*	-.52	-.67	.15
			d	.05	44.8	-.49	-.65	.10
	Kingston	RI	a	1.57	38.8	-.53	-.71	.32
			b	.08	67.5*	-.49	-.67	.24
			c	.25	45.6	-.54	-.73	.35*
			d	.60	84.4*	-.51	-.68	.20
	Brandon	VT	a	1.63	64.5*	-.53	-.69	.18
			b	1.78	55.8	-.47	-.66	.20
			c	.10	28.7	-.50	-.68	.21
			d	1.18	29.5	-.46	-.61	.03
Piedmont	Warm Springs	GA	a	1.14	44.2	-.54	-.69	.20
			b	.14	42.0	-.50	-.65	.13
			c	.09	44.1	-.54	-.70	.24
			d	.78	46.0	-.53	-.69	.19
	Paterson	NJ	a	.55	66.8*	-.53	-.70	.73*
			b	.86	68.9*	-.46	-.62	.02
			c	1.56	33.8	-.49	-.66	.15
			d	1.03	41.5	-.48	-.64	.09

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Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Piedmont	Washington West	DC	a	.02	60.1	-.46	-.63	.09
			b	.19	44.1	-.47	-.64	-.13*
			c	.83	50.3	-.51	-.67	.19
			d	.87	79.1*	-.47	-.64	.12
Blue Ridge	Mount Mitchell	NC	a	.10	23.2	-.52	-.69	.23
			b	.98	39.9	-.49	-.66	.17
			c	1.08	45.9	-.49	-.65	.11
			d	.35	50.3	-.52	-.69	.20
	Strasburg	VA	a	1.07	39.3	-.51	-.67	.16
			b	.90	63.3*	-.51	-.67	.14
			c	.41	48.2	-.50	-.68	[illegible]
			d	.33	31.5	-.48	-.64	.15
	Sherando	VA	a	.73	43.3	-.51	-.67	.16
			b	.72	34.2	-.49	-.63	.06
			c	1.30	45.8	-.49	-.65	.16
			d	.40	76.3*	-.49	-.66	.13
Ozark Plateaus	Ironton	MO	a	1.14	58.8	-.51	-.66	.15
			b	.56	46.4	-.54	-.70	.24
			c	.13	47.5	-.50	-.67	.18
			d	.26	58.6	-.45	-.64	.16
	Saint Paul	AR	a	.05	35.6	-.48	-.64	.08
			b	.41	47.7	-.53	-.70	.26
			c	.79	80.3*	-.54	-.71	.25
			d	.08	60.7	-.54	-.72	.29
	Fidelity	MO	a	.30	56.8	-.60	-.73	[illegible]
			b	1.80	36.0	-.52	-.72	.33
			c	1.32	100.7*	-.49	-.64	.08
			d	.16	31.7	-.51	-.67	.18
Ouachita Mtns.	Horseshoe Mtn.	AR	a	.68	69.3*	-.52	-.69	.26
			b	.56	82.4*	-.49	-.64	.08
			c	1.16	68.4*	-.59	-.72	.24
			d	.47	61.2	-.57	-.73	.29
	Mena	AR	a	1.46	41.3	-.49	-.65	.10
			b	1.53	44.5	-.49	-.66	.15
			c	.53	30.3	-.50	-.67	.13
			d	.65	25.4	-.47	-.64	.13

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Province	Quadrangle	State		$\bar{x}$/st. er.	χ^2_{46}	$\nabla^1\rho_1$	$\nabla^2\rho_1$	$\nabla^2\rho_2$
Ouachita Mtns.	Lavaca	AR	a	.49	86.4*	-.62	-.78	.43*
			b	1.02	39.6	-.51	-.67	.18
			c	1.02	37.3	-.45	-.64	.14
			d	1.06	81.0*	-.50	-.66	.17
Valley and Ridge	Norris	TN	a	.08	34.3	-.51	-.65	.14
			b	.79	51.4	-.56	-.73	.32
			c	.25	58.0	-.46	-.60	-.01*
			d	.08	54.6	-.49	-.65	.10
	Alexandria	PA	a	.87	53.1	-.50	-.67	.18
			b	.61	23.5	-.51	-.66	.18
			c	.60	41.8	-.47	-.65	[illegible]
			d	.10	70.3*	-.42	-.57	-.06*
	Saugerties	NY	a	.14	42.9	-.44	-.60	.01
			b	.07	41.3	-.47	-.63	.08
			c	1.50	83.3*	-.47	-.63	.04
			d	.47	45.8	-.48	-.68	.09
Appalachian Plateau	Ithaca West	NY	a	2.77	61.4	-.41	-.58	0.0*
			b	2.78	35.2	-.51	-.69	.24
			c	1.54	62.6	-.55	-.71	.23
			d	3.53	38.2	-.50	-.69	.26
	Fayetteville	WV	a	.31	73.6*	-.47	-.64	.15
			b	.00	75.1*	-.47	-.65	.17
			c	.21	63.0*	-.53	-.72	.32
			d	.25	82.4*	-.46	-.64	.12
	Whitwell	TN	a	.06	71.7*	-.45	-.64	[illegible]
			b	.45	54.8	-.48	-.64	.08
			c	1.50	57.6	-.47	-.66	.19
			d	.40	40.7	-.50	-.66	.14

test that some structure remains in the pattern of the slope series beyond that explained by the slope wash/creep process model. The ACF's indicate that this structure must be quite minor. Furthermore, there does not appear to be any discernable systematic pattern common to these traverses with significant values. For example, one traverse (Brandon-a) shows significant values at lags 17 and 29. One would be hard pressed to explain such a pattern in any simple manner. Thus, these statistics should be taken as a cautionary warning, but in themselves do not suggest any systematic alternative model. Of the seven tests of residuals, only this one shows any need for caution.

The third test is based upon the fact that when the ACF of the first difference of a white noise series is calculated the values at all lags will be zero except for lag one, where the value -0.50 will be observed. Thus, the ACF of each traverse can be tested to see if that lag value differs significantly from -0.50. An approximate confidence interval can be constructed using as standard error the value obtained under the null hypothesis that the first difference series itself is white noise. That standard error is 0.06, thus an approximate 95% confidence interval is -0.38 to -0.62. As can be seen in Table XII, none of the 96 traverses yield values outside this range. Thus, this test gives no reason to suspect the goodness of fit of the estimated models.

The fourth test arises because the second difference of a white noise series will also display a specific value at lag one, namely -0.67. An analogous test is constructed and in this case the standard error is identical, 0.06. Thus, a 95% confidence interval is -0.55 to -0.79.

Again, it was found that no traverses yield values outside of this range (Table XII). The overall goodness of fit is further reinforced.

The fifth test is also based upon the expected value of a second difference of white noise. In this case it can be shown that, at lag two, a value of 0.17 should appear. All higher lags have an expectation of zero. The approximate standard error in this case is 0.08 giving a 95% confidence interval of 0.01 to 0.33. This test resulted in significant values in 10 of the 96 traverses (Table XII). There does not appear to be any tendency for the values to be too high or too low as six values exceeded the upper limit and four fell below the lower limit. This number of significant values does not appear to be beyond the acceptable limit for a 95% confidence level which is based upon an approximation of the true standard error. Thus, with 86 of the 96 traverses easily passing this approximate test there appears to be no reason to suspect the goodness of fit of the model on the basis of this test.

Summarizing the five tests we have three which reject fewer than would be expected at the 95% level (i.e. zero as opposed to 5), one which rejects about what would be expected, and one which rejects more than would be expected. Combining the results of applying all five tests, giving a total of 480 tests, we see there were 37 rejections for an overall average of 8%. This is so close to the nominal 95% level that there appears to be no good reason to doubt the overall ability of this model to provide adequate goodness of fit to arbitrary traverses. Inspection of Table XII will show that there is no systematic tendency for a particular province or quadrangle or traverse orientation to fail to fit the model. Thus, it seems reasonable to conclude that the results obtained are precisely

the kind of random variability one would expect at the 95% confidence level if the null hypothesis were indeed true. The goodness of fit of the models is as desired.

Tests six and seven are both based upon the partial autocorrelation function. Again they are based upon the assumption that the residual series is not significantly different from white noise. Test six makes use of the fact that the PACF of the first difference of a white noise series will display a value of -1.0 at lag zero and equal $-1/(k+1)$ at successive lags, k. An approximate standard error (based on the assumption that that series itself is white noise) is given by 1/ N where N is the length of the series. Two standard error (approximately 95% confidence level) limits were computed for lags 1 through 7. Beyond the 7th lag the values are not significantly different from zero. Lags for which the partial autocorrelation fell outside of these limits are listed in Table XIII. Since each of the seven lags yields a test, a total of 672 tests are provided. As can be seen only 42 lags or about 6% are significant. This is quite reasonable for a test designed to reject approximately 5% of the results when the null hypothesis is true. Test six does not provide any evidence sufficient to reject the goodness of fit of the models in general. More importantly, no single test yields more than two significant values. There does not appear to be any reason to reject the goodness of fit of the model in any specific instance.

Test seven is available because the PACF of the second difference of a white noise series will decay according to the formula $-2/(k+2)$ at each lag k. Again approximate 95% confidence limits were set up and values of lags one to seven outside these limits are listed in Table XIII. Only

Table XIII. Lags (out of first seven) which are significant in PACF of first difference (∇^1) and second difference (∇^2) of white noise series. Numbers should be read as: 3 means the third lag is significant, not that three lags are significant, zero means no lags are significant.

			Traverse							
			A		B		C		D	
	Province	Quadrangle	∇^1	∇^2	∇^1	∇^2	∇^1	∇^2	∇^1	∇^2
1.	Interior Lowlands	Mammoth Cave	3	0	0	6	0	0	6	6
		Hillsboro	0	0	0	7	6	6	2	0
		Rover	2	5	0	0	0	0	0	0
2.	New England	Ayer	3	3,7	0	0	7	6	0	0
		Kingston	0	0	5	5,7	2	7	0	0
		Brandon	3	0	0	0	0	0	0	0
3.	Piedmont	Warm Springs	0	0	5	0	0	0	0	0
		Paterson	6	5	0	6	0	0	0	0
		Washington West	0	0	0	0	5	0	7	0
4.	Blue Ridge	Mt. Mitchell	0	0	0	0	0	0	0	0
		Strasburg	0	0	0	6	0	0	0	0
		Sherando	0	0	0	6	0	0	3	3
5.	Ozark Plateaus	Ironton	5	7	7	0	0	0	4	0
		St. Paul	0	7	4	0	0	0	0	0
		Fidelity	0	1	2,6	6	0	0	0	0
6.	Ouachita Mtns.	Horseshoe Mtn.	0	0	0	0	3,5	5	3,5	0
		Mena	0	0	0	0	3	0	0	0
		Lavaca	2	3	0	0	0	5,6	5	7
7.	Valley and Ridge	Norris	0	5,6,7	0	0	5	5,6	0	0
		Alexandria	0	0	0	7	0	4,6	2,4	0
		Saugerties	0	0	0	0	5	0	4	0
8.	Appalachian Plateaus	Ithaca West	0	0	0	0	3	0	0	0
		Fayetteville	6	0	0	0	2	0	0	0
		Whitwell	0	0	0	0	4	0	0	6

34 of 672 values fall outside the expected range. Since about 5% are significant and about 5% would be expected at this confidence limit there is no evidence to reject the goodness of fit of the models in general. Again, there is also no specific evidence to reject the goodness of fit in any particular case. It appears that all traverses are modelled adequately using the ARIMA (2,1,0) model and the estimated parameters.

Because tests six and seven actually comprise 1344 separate tests a further examination of the results can be made which sheds light on the actual results. To motivate this test we note that one traverse (Norris-a) actually yielded three significant lags; is this enough to suspect the goodness of fit of the Norris-d model? After all this is a 43% rejection rate. First note that any rejection, even one, would exceed the 5% rejection rate expected (giving a 14% rate). And yet in 672 tests we can expect many to reject one lag. Thus, it is the overall pattern which is most important. Part of that pattern is given by the number of times no lags, one lag, two lags, three lags, etc. were actually rejected. Under the null hypothesis and at the confidence level chosen each test may reject or not with a probability of 0.05. An idea of how many times 0,1,2,3, etc. rejections can be expected even if the null hypothesis is correct can be obtained by application of the binomial theorem. We take each traverse ACF to be a binomial experiment consisting of seven trails. A total of 192 such experiments have been performed. With $N=192$, $n=7$, $p=0.05$ and $q=0.95$ we will expect the following results:

number of lags significant	number expected	number observed
0	134	132
1	49	50
2	8	9
3	1	1
	192	192

As can be seen there is no indication of any pattern in the observed results. They can be considered independent realizations of a random variable (exceeds 0.95 or limit or not) which has $p=0.05$. This test provides further firm evidence that the model fits the observed data well.

Having demonstrated that the ARIMA (2,1,0) model is reasonable and that the estimated parameters are in general compatible with the expected range, it is now appropriate to summarize the estimates of these parameter values. In Table XIV are the means of the four traverses in each quadrangle. Also listed are the mean values for each province and the grand mean computed from all 96 traverses. As can be seen, there is a considerable range in the mean values for provinces ($0.64 < \bar{\phi}_1 < 0.84$, $-0.12 < \bar{\phi}_2 < 0.01$) which in general is considerably larger than the variance within provinces. This is especially noticeable in the case of the $\hat{\phi}_1$.

There is obviously the suggestion that there are significant differences from province to province in the values of ϕ_1 and possibly of ϕ_2. One must

Table XIV. Summary of parameter values for each quadrangle.

	PHI 1				PHI 2			
	QUAD							
Province	1	2	3	MEAN	1	2	3	MEAN
Interior Lowlands	0.75	0.77	0.74	0.75	-.10	-.08	-.16	-.11
New Englend	0.78	0.76	0.82	0.79	.00	-.02	.05	.01
Piedmont	0.86	0.80	0.80	0.82	-.10	-.09	-.18	-.12
Blue Ridge	0.84	0.64	0.68	0.72	-.21	.13	.06	-.01
Ozark Plateaus	0.82	0.71	0.72	0.75	-.13	-.18	-.01	-.11
Ouachita Mtns.	0.69	0.61	0.62	0.64	-.02	-.07	.03	-.02
Valley and Ridge	0.75	0.76	0.66	0.72	.04	.01	-.12	-.02
Appalachian Plateaus	0.82	0.71	0.72	0.75	.00	-.10	.04	-.02
QUAD MEANS	0.79	0.72	0.72		-.06	-.05	-.04	
GRAND MEAN				0.74				-.05

also consider the possibility that within provinces there may be significant differences from quadrangle to quadrangle. It is also of some interest to evaluate whether there is a significant tendency for one traverse orientation to vary from another orientation in terms of these parameter values. These questions have been examined by means of an analysis of variance performed on each parameter separately.

The analysis structure is as follows. There are three factors whose effects upon the parameters is of interest: province, quadrangle (i.e. area within province), and traverse (i.e. orientation). Province is measured at eight levels, quadrangle at three in each province, and traverse at four within each quadrangle. The analysis is a random effects model for all three factors; if it were redone, new levels would almost surely be included. The quadrangle factor must be considered nested within the province factor since it is not possible to find the same quadrangle in some other province. Although traverse could be considered to be nested within quadrangle for this study the orientation of the traverse was the phenomena of interest. In that case a traverse of each orientation can be observed in each province at each quadrangle. Thus, the factor traverse was considered to be crossed with province, so that in addition to province, quadrangle nested in province, and traverse another source of variation whose effect was computed was the province x traverse interaction. The error term was estimated by the quadrangle by traverse interaction nested within province which had 48 degrees of freedom in each test. This was used to test both the province by traverse interaction and the traverse main effect. A second error term, the quadrangle nested in province effect, was used to test the main effect

of province unless it was found to be not significant, in which case the other error term was also used for this test since with more degrees of freedom it could be expected to provide a better estimate of the true error term. The computed analysis of variance tables are given (Tables XV and XVI).

In the case of ϕ_1 only one source of variation was found to be significant. That is, the main effect of province. All other sources of variation yielded remarkably consistent mean squares which were nearly identical to that estimated from the "error" term.

The analysis of variance for ϕ_2 shows that the quadrangle effect is significant. The mean square due to province is actually slightly larger but because its expected mean square includes a contribution from the quadrangle effect that term was used as the error term in computation of the F-ratio. It was thus found that the province factor is not significant. Differences between provinces are no greater than can be found within a single province in going from one area to another. Note that, according to the hypothesized model, the coefficient phi 2 is equal to the negative of the rate of creep, thus these results apply to the creep rate coefficients equally as well.

Since the hypothesized model is so well supported by the available data, it is reasonable to explicitly break out the slope wash rate coefficient and study its variability from area to area. Recall that phi 1 is the total rate equal to the sum of the creep and slope wash rates. Thus, the sum phi 1 plus phi 2 is an estimate of the slope wash rate. This rate was calculated for the 96 traverses and an analysis of variance run using the same design as previously. Table XVII shows the results.

C-2

Table XV. Analysis of variance for PHI 1. An asterisk ("*") indicates significance at the 95% confidence level, "N.S." means not significant.

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Square	Error Term	F Ratio	Significance
Province	A	7	.241	.034	CB(A)	2.43	*
Quad(A)	C(A)	16	.201	.013	CB(A)	.93	N.S.
Traverse	B	3	.027	.009	CB(A)	.64	N.S.
	AB	21	.227	.011	CB(A)	.79	N.S.
"Error"	CB(A)	48	.649	.014			
Total		95	1.345	.014			

Table XVI. Analysis of variance for PHI 2, equal to the negative of the creep rate coefficient. Abbreviations as in previous table.

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Square	Error Term	F Ratio	Significance
Province	A	7	.244	.035	C(A)	1.17	N.S.
Quad(A)	C(A)	16	.485	.030	CB(A)	2.73	*
Traverse	B	3	.010	.003	CB(A)	.27	N.S.
	AB	21	.247	.012	CB(A)	1.09	N.S.
"Error"	CB(A)	48	.517	.011			
Total		95	1.504	.016			

Table XVII. Analysis of variance for estimated slope wash rate coefficient. Estimates are computed from the sum PHI 1 plus PHI 2. Abbreviations as in previous tables.

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Square	Error Term	F Ratio	Signif- icance
Province	A	7	.283	.040	C(A)	1.25	N.S.
Quad(A)	C(A)	16	.508	.032	CB(A)	3.56	**
Traverse	B	3	.012	.004	CB(A)	.44	N.S.
	AB	21	.179	.009	CB(A)	1.00	N.S.
"Error"	CB(A)	48	.451	.009			
Total		95	1.434	.015			

As with creep, the quadrangle term is found to be significant indicating that creep varies from area to area within a single physiographic province. As with creep, any apparent differences between provinces can be attributed to the particular sites selected for comparison. Again, travese orientation has no effect on its own, and the interaction term (traverse by province) also shows that no differences in slope wash rate estimates results even when comparing one traverse direction in one province to a different traverse direction in some other province.

To illustrate the differences in the values of phi 1 (overall process rates) that can be seen between provinces and to determine which, if any, provinces could be considered to behave similarly, a multiple comparison test utilizing the Least Significant Difference method (Figure 15 and Table XVIII). As can be seen in the table, at most three distinct groupings of overall process rates could be defined. As can be seen from the overlap in group assignments, no distinct separation is possible and it might appear just as reasonable to consider the variation to be a continuoum. A more conservative comparison procedure, Tukey's "Honestly Significant Difference" technique suggests that at most two groupings could be defined (Table XIX). It is important to note that neither method would allow all provinces to be assigned to a single group. However, there is one (extremely) conservative multiple comparison method, namely Sheffe's Test, which considers all possible comparisons, that does group all provinces together. This is not consistent with the ANOVA results and one of the other groupings, probably the middle one, Tukey's HSD, is to be preferred. Following that method, we consider the Ouachita Mountains to have a low process rate and the remaining provinces to have a (comparatively) high process rate.

Table XVIII. Least significant difference test on parameter ϕ_1.

Multiple Comparisons on Factor PROVINCE

Level	Mean	Sample Size	Separation
6	.64	12	a
4	.72	12	ab
7	.72	12	ab
8	.75	12	bc
5	.75	12	bc
1	.75	12	bc
2	.79	12	bc
3	.82	12	c

Least Significant Difference

Error mean square = .014
Degrees of freedom = 48
Alpha level = .05
Table value from Student's t = 2.01
LSD value = 9.709

Figure 15. Diagram illustrating the differences in mean values of provinces and error bars derived using the least significant difference test. Province level numbers are keyed to those in Table XIII.

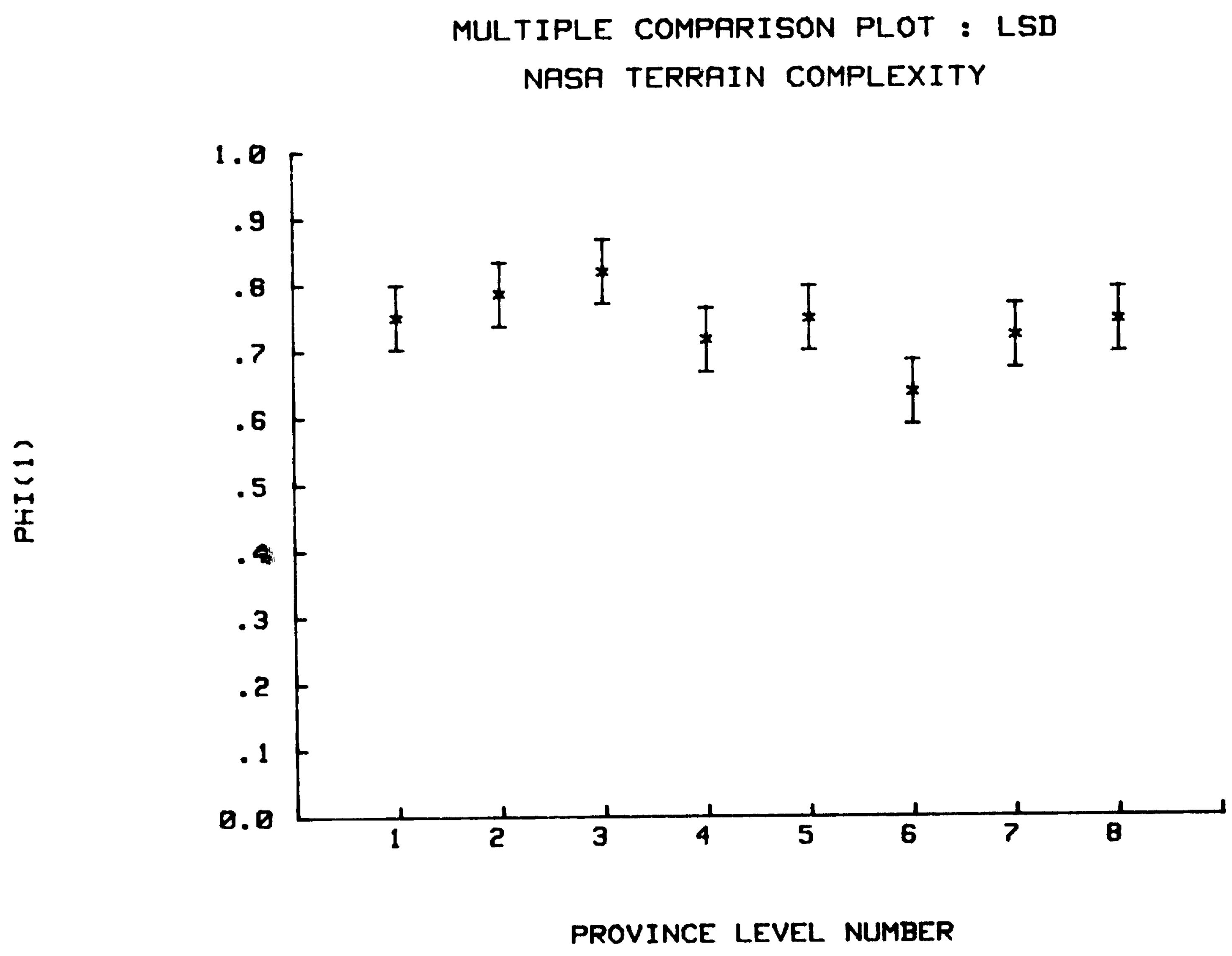
MULTIPLE COMPARISON PLOT : LSD
NASA TERRAIN COMPLEXITY
PHI(1)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
1
2
3
4
5
6
7
8
PROVINCE LEVEL NUMBER

Table XIX. Tukey's Honestly Significant Difference test on parameter ϕ_1.

Multiple Comparisons on Factor PROVINCE

Level	Mean	Sample Size	Separation
6	.64	12	a
4	.72	12	ab
7	.72	12	ab
8	.75	12	ab
5	.75	12	ab
1	.75	12	ab
2	.79	12	ab
3	.82	12	b

Tukey's HSD

Error mean square = 0.014
Degrees of freedom = 48
Alpha level = .05
Table value from Studentized range = 4.48
HSD value = .153

V. INTERPRETATIONS

Because of the speculative nature of this study there are a number of items that should be described separate from the results *per se*. These are separated from the *conclusions* section because they are more precisely considered to be geomorphic *interpretations*. Conclusions pertinent to the geobotanic applications intended in this study -- which are, in large part, based upon these geomorphic interpretations -- will be discussed in a succeeding chapter.

When measured at the scale of this study it is definite that there are measureable relations between adjacent slopes in a traverse of the landform. Such relations are appropriately described by the postulated ARIMA (2,1,0) model. Using this model good estimates of the rate of landform modification by the two processes - slope wash and creep, *sensu lato* - may be obtained. In particular, $-\phi_2$, is an estimate of the rate of creep within the area. Slope wash rate is given by $\phi_1 + \phi_2$. Thus ϕ_1 is an estimate of the overall rate of landform modification. Because of the considerable variability in these rates which can be observed to occur even within a small area (the size of a quadrangle), it is best to use the averages of several traverses when comparing regions. In general, it appears that the rate of landform modification by slope wash greatly exceeds the rate of creep. Even in a single traverse the rate of slope wash is usually twice that of creep. That the rate of slope wash exceeds that of creep agrees with the findings of Carson and Kirkby (1972, p.199). No traverse in the entire group studied yielded estimates of creep as large as that of slope wash. Variability in the rates of the two processes is apparently about the same.

The analysis of variance has shown that real differences do exist in the degree of relation between adjacent slopes in the various regions studied. The overall rate of landform modification (as measured by phi 1) varies from province to province. There is an indication that there is a continuous variation in such rates. However, the Tukey HSD test implies that at least two distinct levels of rates are found. A reasonable interpretation is that the Ouachita Mountains province is modified at a distinctly lower rate than the remaining provinces. Such differences apply to the overall rates but cannot be ascribed to either slope wash or creep specifically, only to their combined activity.

Analysis of phi 2 (creep) and the sum phi 1 plus phi 2 (slope wash) shows that the variability of these rates is at a finer scale than the province level. Significant differences in these rates cannot be demonstrated between provinces but do exist from quadrangle to quadrangle within provinces. Such differences are much larger than the province to province variations. Thus, there are regional differences in the rates of both creep and slope wash which do not show any systematic relation to province. This could very well reflect local variations in controlling factors such as lithology or structure as well as the variations in climate. Interestingly, the three analyses together imply that the overall process rates are quite constant within any province and since both of the component rates do vary significantly within the province, it seems that decreases in one rate within a province are made up by increases in the other. As will be seen in the final chapter there appears to be a negative relation between slope wash and creep rates, thus it would appear that overall process rate may be a significant basic (and perhaps underlying) feature of each physiographic province.

Importantly, it is clear that the degree of relation between adjacent slopes estimated (i.e. the rates) do not depend at all upon the orientation of the traverse being considered. This is true for phi 1, phi 2, slope wash and creep. Such a finding means that detailed study of rates within an area the size of a quadrangle is not required. Even one traverse is sufficient. Perhaps study of a single traverse in each of several adjacent quadrangles would yield better estimates of the regional rates.

Finally an important observation arising from these studies is a distinction between form and process. In particular, it is important to recognize that the techniques discussed yield estimates of the rates of processes responsible for forming the slopes. These are always past rates which may or may not correspond to present rates. Rates may change considerably faster than the slope forms can respond. An example may be given by the Brandon, Vermont quadrangle in the New England physiographic province. This is an area of sharp relief significantly carved by continental glaciation during Late Wisconsinan times. These forms are only partially modified by subsequent processes. On the other hand, phi 1, the estimate of overall process rate, is 0.82 for that quadrangle. This is a very high value, exceeded in only two other quadrangles of the 24 studied. Such a value could very well reflect higher process rates shaping the landform under (perhaps) periglacial conditions.

VI. CONCLUSIONS

Process rates affecting the regolith can be estimated from available topographic maps. In general, mean values will be about 0.75 ± 0.15 for any area and all values within the area will be within ± .12 of one another. Such rates give an estimate of how rapidly the slope forms are being modified by slope wash and creep. This, in turn, should be related to the rate of weathering of the underlying regolith and bedrock. If this bedrock contains ore bodies the strength of their signal in the regolith can be expected to be influenced strongly by the rate of which that regolith is developing. Thus, we can expect that our ability to use geobotanical exploration will be related to the measure of overall process rate given by phi 1.

Although overall process rates remain at a consistent level within a given physiographic province (i.e. there is no significant quadrangle effect on phi 1) the process mix can still vary significantly from area to area within that province. Thus, both slope wash and creep vary significantly from area to area within a given province. The particular mix that occurs in an area can be expected to strongly influence the strength of a geobotanical signal of an ore body. In particular, slope wash tends to carry material far downslope and thus spread it over a large area. In contrast materials are moved slowly and only short distances by creep. Thus, in areas in which creep is relatively strong the geobotanical signal of an ore body should also be relatively strong. Where the slope wash effects are especially large the rate of regolith removal may be to great to allow significant geobotanical signals of ore bodies to build up. Thus, such investigations should be emphasized in regions with a large (in a negative sense) value of phi 2.

Because of phi 2 term is so small, and in many cases is not significantly different from zero, it is apparent that the AR(1) portion of the model dominates (in a slope model). Thus, the arguments of Craig (1982) probably give a very close approximate measure of the scale of the landform in a given area. It has been shown that this terrain scale also affects the properties of remote sensing data. That the phi 1 term dominates in defining landform scale seems quite reasonable in that it is a measure of the overall rate at which processes shape that form. In general, the more active the processes the larger an area the ore body signal can be expected to be spread over. Thus, the spacing of samples in geobotanical investigations should increase as the value of phi 1 increases. Estimates of the spacing using the value of phi 1 can be computed from the formula in Craig (1982).

VII. FUTURE WORK

On the basis of the concepts and results discussed above six major areas of additional work can be defined. At present so little work has been done relating form and process in a quantitative manner that our understanding is perhaps just at a threshold. Whether significant progress can be expected in the future depends upon how clearly the path of future investigations is defined. Some gaps in our knowledge are listed below.

Ensuring the accuracy of the data collection method is a critical need. It has been shown that a large number of errors naturally arise using the methods now employed. These methods include interpolation between contour lines, physically recording data and manual keying it into the computer. Each of these steps introduces errors which are difficult and time-consuming to detect and correct; and of course this necessarily introduces a new step in the procedure. An example of the enormous effect of a single error will illustrate the need to avoid such errors and minimize their probability of occurrence. Traverse C of the Ayer quadrangle contained an error at point 52. Table XX summarizes some parameters computed from the data before and after the correction was made. It is clear that such an error is sufficient to make the results useless. It is fortunate that such errors have an effect which is dramatic and hence makes them obvious.

Three techniques to avoid such errors have been considered and are presently undergoing evaluation. Each is based on the idea that the data should go directly into the computer in one step rather than a multi-step operation. The first method would make use of the digital terrain models available from the United States Geological Survey (U.S.G.S.)

Table XX. An example of the effects of a single error upon the estimates of various statistics. Traverse C, Ayer MA.

Parameter	Error	Corrected
Rho (1)	0.303	0.818
Rho (2)	0.324	0.700
Estimate of Phi (1)	0.82	0.74
Estimate of Phi (2)	-0.09	0.10
Final Phi (1)	0.11	0.77
Final Phi (2)	0.51	0.09
Chi-squared for ACF	23.7	67.5

for some quadrangles. Such models are contained on magnetic tapes and contain enough data, in grid form, to construct the topographic maps. This data can be extracted directly and input to the autocorrelation programs. Unfortunately, only a small percentage of the total area of the U.S. has yet been so mapped. And, of course, virtually nowhere else in the world will such maps be available in the foreseeable future. Consequently, other error-free methods must still be available.

A second method is to use a digitizer to follow the same traverse. This time instead of equal intervals we digitize the points at which the contour lines cross and indicate whether we are going uphill or down. From this information the computer can be used to reconstruct the cross-section and exact linear interpolation can be used. Even more sophisticated interpolation is easily achieved; presently cubic interpolation appears to be most desireable.

Another procedure being explored is to interpolate mentally as before but to input the resulting data directly using speech recognition techniques. Although slower and probably less accurate than digitizing, it is still much faster and more precise than the old manual method.

Besides the means of data input, data collection can also be improved in several ways. It would be useful to determine the effects of changing the sample spacing within a traverse. Perhaps the same level of precision could be achieved using 2 mm rather than 1 mm spacing. There is some indication that changing the sample spacing will have a systematic and predictable effect upon the parameter estimates. This is true for a pure ARIMA (1,d,0) model (Craig, 1982). Whether it can also be demonstrated for an ARIMA (2,d,0) model needs to be examined.

Other changes in data collection could include taking fewer traverses per quadrangle, since one is apparently enough and orientation does not introduce a bias. Whether replicates in adjacent quadrangles are desireable should be examined. The large effects of errors makes it desireable to introduce more tests for errors in a systematic fashion. Since errors in effect add a 'noise' series to the true data a more complete analysis of the theoretical effects of added noise upon the model structure would be of use.

A second major area of concern in future studies should be the extent to which these results and in particular the proposed ARIMA (2,1,0) process/form model can be extended to other area. At a minimum samples should be taken from each physiographic province in the U.S. Preferably, estimates of process rates should be available from every physiographic section in the U.S. Such a study is, in fact, presently underway (NASA Grant NAG 5-166 to KSU). These data should make it clear whether mass wasting processes (mudflows, rockfalls, landslides, slumps, etc.) add a significant new structure to the autocorrelational properties of slopes. Some samples will be taken from areas known to be dominated by such processes.

In general, it would be wise to apply this method of estimating process rates to areas where previous studies have documented the actual process mix based upon field observations. A number of such studies, spread throughout the world, have been documented in the literature. The two methods of estimation should be compared directly.

Such studies are relatively rare and tend to concentrate on one process rather than a total evaluation. Thus, the most critical test of the postulated model will probably only come if field examinations are

specifically designed to evaluate the accuracy of its predictions in the field. Perhaps the simplest of such tests would arise when field work occurs in areas of extremes of the processes. Examples which could be appropriate include: badlands areas, areas of dunes, tropical regions and the dry valleys of the Antarctic. Estimation of process rates in the field is a difficult and time-consuming task. Because of the seasonal and yearly variations in the true rates such studies would ideally extend over a number of field seasons. The techniques of such studies are fairly well worked out (Goudie, 1981). It will take a significant committment of time and resources to achieve this objective.

We can expect that a number of studies of geomorphic interest can be pursued with such process-rate data available. As an example, consider the question: are the rates of surface wash and creep related? The results of the analysis of variance tests had suggested that an increase in one should be accompanied by a decrease in the other so that the sum for a province remains constant. This suggests the following, let k be the province sum, b the creep rate and a the rate of slope wash, then:

$$k = a + b$$

$$a = k + (-1)*b$$

We have a classic regression model relating the two rates in which the intercept equals the province sum and the slope of the line is minus one. A plot of the actual data (Figure 16) shows the inverse relation as expected. However, the estimated slope is not -1, rather it is -.56 and the intercept does not equal the mean overall rate .74, rather it is .43 (Table XXI). Perhaps this discrepancy arises because all 96 traverses of

Figure 16. Regression plot of creep (independent) and slope wash rates. Quadratic curve is significant at the 95% level.

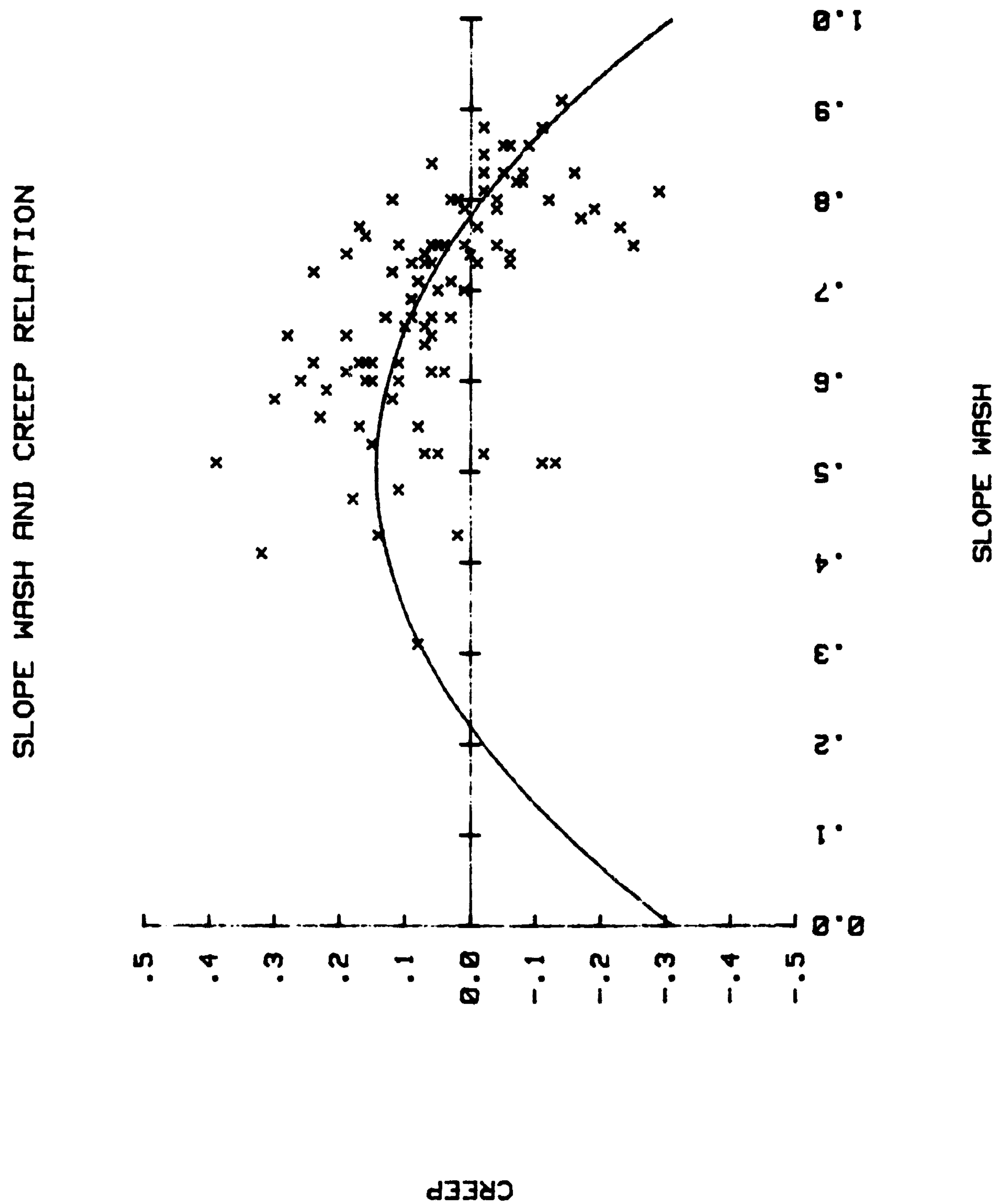
SLOPE WASH AND CREEP RELATION
SLOPE WASH
CREEP
0.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5

Table XXI. **Analysis of variance table of polynomial regression of creep rate (dependent variable) versus slope wash rate (independent variable).**

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio
Linear	1	.442	.442	43.08
Quadratic	1	.108	.108	10.52
Residual	93	.954	.010	
TOTAL	95	1.504		

data are lumped together in one regression. The ANOVA results would suggest that the relation would show up when considering the data of individual provinces. It should be examined in more detail. Surprisingly, the linear regression is significantly improved upon by a quadratic one (Table XXI). This seems to suggest that creep reaches a maximum when surface wash takes a middle value and decreases at lower or higher values. This is conceivable in that high values of surface wash might remove material before creep can move it and low values of surface wash (presumably in an area of low rainfall or one lacking regolith) would be accompanied (in a dry area) by lack of moisture to lubricate and enhance the creep process. Whether the relation is truely quadratic cannot be demonstrated until more data from areas of low slope wash rates are available. If the quadratic result is shown correct on the basis of additional data, one can expect at least one ANOVA result to change also. It is clear that many interesting geomorphic studies are possible with such data.

Additional geomorphic questions which can be examined with such data should emphasize the relation of the process rates to variables which could be responsible for them. Such variables include:

i) temperature

ii) precipitation

iii) elevation

iv) thickness of regolith

v) erodibility of bedrock

vi) vegetation cover

Certain of these data are easily collected. Others require much more work. Expecially the latter three would probably require field work to estimate well. It is natural to expect these process rates to be related to the rate of denudation in an area. Technically, the rates estimated using the ARIMA (2,1,0) model are the rates these processes acted at during the time that the landform was shaped to its present form. In spite of the technical difference a relation between process rates and denudation rates would not be surprising to see and would certainly be useful to know of. Another question of considerable interest is whether process rate estimates will differ depending on whether the slope processes are dominantly transport limited or weathering limited. The autocorrelational structure of these two classes of slopes should be compared and contrasted.

It is now clear that slope traverses follow a specific model of autocorrelation. This means that the angle of a slope is related to that of adjacent slopes. Because slope angle has a significant effect upon the distribution of reflected light from that slope, it can be expected that sequences of reflected light measurements along a traverse of the ground (such as represented by LANDSAT data) will also show an autocorrelation structure. That such a structure actually exists has been demonstrated (Craig, 1979; Craig and Labovitz, 1980). It also appears that it is related to properties of the terrain below (Craig, 1981). It remains to be demonstrated that there is a direct link between the two data structures. This would be appropriately studied by means of transfer function theory (Box and Jenkins, 1970). Such a study remains to be done but is now appropriate.

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APPENDICES

Province	Quadrangle	State		Sigma Elev.	g_1	g_2	χ^2	Dif.
Interior Low	Mammoth Cave	KY	a	76	-.36	-1.40	---	---
			b	75	-1.14	.15	---	---
			c	100	-.68	-.34	---	---
			d	49	.56	-.01	---	---
	Hillsboro	KY	a	48	-.39	.04	27.44	8
			b	40	-.50	-.21	18.32	6
			c	41	.02	-.93	47.68	6
			d	37	-.37	-.67	11.50	5
	Rover	TN	a	12	.11	-.65	5.97	3
			b	19	-.16	-.17	11.47	7
			c	25	1.27	1.71	91.01	8
			d	22	.93	.65	170.93	6
New England	Ayer	MA	a	37	1.61	2.00	195.54	11
			b	33	.76	-.58	191.14	10
			c	55	.35	-.25	73.89	20
			d	35	1.30	1.00	181.87	10
	Kingston	RI	a	24	1.77	3.71	---	---
			b	31	.52	-.80	---	---
			c	33	1.56	1.54	---	---
			d	26	1.46	1.18	---	---
	Brandon	VT	a	289	1.35	.47	427.21	21
			b	257	1.24	.37	395.70	20
			c	36	-.18	-.49	67.65	6
			d	184	1.59	1.18	548.14	14
Piedmont	Warm Springs	GA	a	69	.23	-1.64	---	---
			b	33	-.03	.05	---	---
			c	32	.25	-.72	---	---
			d	37	.09	-.34	---	---
	Paterson	NJ	a	143	.36	-.86	245.54	22
			b	116	-.19	-.95	67.96	19
			c	64	.17	-1.28	246.20	10
			d	162	.15	-1.49	321.50	23
	Washington West	DC	a	97	-.07	-1.08	---	---
			b	77	-.18	-.35	---	---
			c	67	-.72	-.54	---	---
			d	95	-.19	-1.14	---	---

Province	Quadrangle	State		Sigma Elev.	g_1	g_2	χ^2	Dif.
Blue Ridge	Mount Mitchell	NC	a	476	-.61	-.30	---	---
			b	705	.70	-.46	---	---
			c	157	.71	.50	---	---
			d	442	.02	-1.09	---	---
	Strasburg	VA	a	425	.81	-.46	---	---
			b	87	-.16	-1.16	---	---
			c	314	.88	.02	---	---
			d	514	.28	-1.49	---	---
	Sherando	CA	a	463	-.47	-1.08	---	---
			b	335	-.20	-.68	---	---
			c	597	-.41	-1.40	---	---
			d	586	.45	-1.11	---	---
Ozark Plateaus	Ironton	MO	a	198	.60	-1.21	---	---
			b	127	-.29	-.81	---	---
			c	198	.52	-.72	---	---
			d	204	.86	-.83	---	---
	Saint Paul	AR	a	176	.72	-.47	---	---
			b	158	.10	-.61	---	---
			c	278	-.10	-1.47	---	---
			d	144	.35	-.97	---	---
	Fidelity	MO	a	25	-.62	-.74	---	---
			b	31	-1.15	.92	---	---
			c	41	-.24	-1.35	---	---
			d	25	-1.43	3.13	---	---
Ouachita Mountains	Horseshoe Mountains	AR	a	63	.57	-.37	---	---
			b	82	-.86	.47	---	---
			c	72	.32	1.48	---	---
			d	63	-.15	1.28	---	---
	Mena	AR	a	35	-.13	1.01	---	---
			b	40	-.07	-1.41	---	---
			c	28	.52	.78	---	---
			d	28	.45	-.71	---	---
	Lavaca	AR	a	34	-.37	-1.07	---	---
			b	55	2.46	6.73	---	---
			c	48	2.06	4.54	---	---
			d	46	.75	-.42	---	---

Province	Quadrangle	State		Sigma Elev.	g_1	g_2	χ^2	Dif.
Valley and Ridge	Norris	TN	a	89	1.06	1.38	55.12	14
			b	35	.56	.27	48.01	6
			c	114	1.25	.94	259.94	20
			d	89	-.13	-.63	81.85	18
	Alexandria	PA	a	153	.96	-.41	711.06	24
			b	34	.86	.09	100.46	4
			c	136	.26	-1.03	278.41	25
			d	165	1.46	.48	1128.59	23
	Saugerties	NY	a	62	-1.06	-.27	---	---
			b	75	-.60	-.94	---	---
			c	52	2.17	3.29	---	---
			d	63	.34	-1.20	---	---
Appalachian Plateaus	Ithaca West	NY	a	280	-.58	-.70	178.65	17
			b	150	-.60	-.46	144.46	16
			c	95	-1.80	2.26	492.17	12
			d	314	-.92	-.60	768.51	22
	Fayetteville	WV	a	325	-1.15	.46	---	---
			b	242	-2.38	4.85	---	---
			c	262	-1.53	2.28	---	---
			d	329	-.56	-1.09	---	---
	Whitwell	TN	a	566	-.04	-1.72	749.01	33
			b	167	-.87	-.49	328.90	25
			c	342	-.99	-.09	433.06	26
			d	522	-.29	-1.55	749.29	34

```
10    ! *****************************************************************
20    ! *                                                               *
30    ! *    PLOTS CROSS SECTIONS FOR 51 QUADRANGLES THROUGHOUT U.S.    *
40    ! *    CHECKS FOR ERRORS IN THE SEQUENCES.                        *
50    ! *                                                               *
60    ! *    WRITTEN APRIL, 1982  BY RICHARD G. CRAIG    FOR NASA STUDY *
70    ! *                                                               *
80    ! *****************************************************************
90    OPTION BASE 1
100   INTEGER A(16381)
110   DIM Elevations(301,4),Elevs_temp(500,1)
120   DIM T$[80],Vn$(50)[10],Sn$(100)[10],Sc(100)
130   DIM Names$(51)[20],Letter$(4)[1],File_names$(51)[6]
140   DIM Names_order(51),State_order(51),Name_order(51),Nasa_quads(51)
150   DIM Lat_quad(24),Long_quad(24),Cont_interval(24),Quad_year(24)
160   DATA "BRANDON,          VT","ITHACA WEST,       NY","LAKE SCOTT,        KS",
"ALEXANDRIA,        PA"
170   DATA "HOT SPRINGS,      SD","NORRIS,            TN","CUMBERLAND,        MD",
"TICONDEROGA,       NY"
180   DATA "THOUSAND SPRINGS, ID","SAN LUIS REY,      CA","JUNIATA ARCH,      CO"
190   DATA "EAST BROWNSVILLE, TX","ANVIL POINTS,      CO","SHEEP MT.,         SD",
"MENAN BUTTES,      ID"
200   DATA "VOLTERRA,         ND"
210   DATA "JACKSONVILLE,     FL","EWING,             KY","JORDAN NARROWS,    UT"
220   DATA "NEW BRITAIN,      CT","LITTLE CREEK,      DE","MAUMEE,            OH"
230   DATA "CAMDEN,           MO","MULLIN,            SC","PROVINCETOWN,      RI"
240   DATA "AYER,             MA","HILLSBORO,         KY","ROVER,             TN"
250   DATA "WHITWELL,         TN","PATERSON,          NJ","DERBY,             CO"
260   DATA "DELAWARE,         MI","JENKS,             OK","LAKE WALES,        FL"
270   DATA "KINGSTON,         RI","MAVERICK SPRINGS, WY"
280   DATA "WASHINGTON WEST,  DC","MAMMOTH CAVE,      KY","ST PAUL,           AK"
290   DATA "FAYETTEVILLE,     WV","WARM SPRINGS,      GA","IRONTON,           MO"
300   DATA "MOUNT MITCHELL,   NC"
310   DATA "HORSESHOE MTN.,   AK","SAUGERTIES,        NY","LAVACA,            AK"
320   DATA "STRASBURG,        VA","FIDELITY,          MO","SHERANDO,          VA"
330   DATA "MENA,             AK","XXXXXXXXXXXXXXX,  XX"
340   MAT READ Names$
350   DISP "SORTING DATA"
```

```
360   MAT SORT Names$(*)[19;2] TO State_order
370   MAT SORT Names$(*) TO Name_order
380   DATA "A","B","C","D"
390   MAT READ Letter$
400   DATA 6,22,0,20,0,19,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,4,2,3,24,8,0,0,0
,0,5,0,9,1,14,23,7,13,10,16,21,18,11,15,12,17,0
410   MAT READ Nasa_quads
420   DATA 43.75,42.375,40.5,36.125,42.5,38.25,35.625,35.125,40.875,41.375,38.87
5,37.125,35.75,38,32.875,37.5,35.75
430   DATA 34.75,42,35.25,38.875,37,37.875,34.5
440   MAT READ Lat_quad
450   DATA 73,76.5,78,84,71.5,83.625,86,85.5,74.125,71.5,77,86,93.75,81,84.625,9
0.625,82.25,94.25,73.875,94.125,78.25,94.25,78.875,94.125
460   MAT READ Long_quad
470   DATA 20,10,20,20,10,20,10,20,10,10,10,20,40,40,20,20,40,20,10,20,20,10,40,
20
480   MAT READ Cont_interval
490   DATA 0606,1969,1972,1973,0404,1951,1949,1965,0808,0505,0909,1965,1973,1976
,1971,1968,1010,1958,1963,1971,1966,1978,1980,1975
500   MAT READ Quad_year
510   DATA "BRAND","ITHW.","LKSCT","ALEX.","HOTSP","NORIS","CUMBR","TICON","THOU
S","SLREY","JARCH","E.BWN","ANVILP","SHEEP","MENAN","VOLT."
520   DATA "JACKS","EWING","JORDN","NEWBT","LITCR","MAUME","CAMDN","MULLN"
530   DATA "PROV.","AYER-","HILLS","ROVER","WHIT","PATER","DERBY","DELAW","JENKS
","LWALE","KINGS","MSPRG"
540   DATA "WASHW","MCAVE","SPAUL","FAYET","WARM","IRON","MITCH","HORSE","SAUG"
550   DATA "LAVAC","STRAS","FIDEL","SHERA","MENA","XXXXX"
560   MAT READ File_names$
570   CALL Beeper(2,5)
580   DISP "INITIALIZING PLOT"
590   CALL Beeper(3,5)
600   DISP ""
610   CALL Quad_name_table(Names$(*),Name_order(*),State_order(*),Names_order(*)
)
620 More_plots:Want_plot=1
630   INPUT "WOULD YOU LIKE TO LOOK AT A PLOT? (1=YES, 0=STOP)",Want_plot
640   IF NOT Want_plot THEN CALL Endplots
650   Quad=17
660   INPUT "WHICH QUADRANGLE WOULD YOU LIKE TO SEE? (0=ALL, XX=ITHACA WEST,NY)"
,Quad
670   IF Quad THEN Quad=Names_order(Quad)
680   Contour_int=Cont_interval(Nasa_quads(Quad))
690   REPEAT
700     Check$="Y"
```

```
710     INPUT "DO YOU WANT ERROR CHECKING OF THE DATA? (Y/N)",Check$
720   UNTIL (Check$="Y") OR (Check$="N")
730   IF Check$="Y" THEN
740     K=4
750     INPUT "DIFFERENCE FACTOR FOR ERROR CHECK? (4)",K
760   END IF
770   Name_length=LEN(File_names$(Quad))
780   Min_elev=9999999
790   Max_elev=-9999999
800   FOR Traverse=1 TO 4
810     ON ERROR CALL No_disk
820     MASS STORAGE IS ":H8,0,0"
830     ASSIGN #1 TO File_names$(Quad)[1;Name_length]&Letter$(Traverse),Return_v
ar
840     IF Return_var THEN
850       MASS STORAGE IS ":H8,0,1"
860       ASSIGN #1 TO File_names$(Quad)[1;Name_length]&Letter$(Traverse),Return
_var
870     END IF
880     OFF ERROR
890     IF Return_var THEN CALL No_file(Return_var)
900     READ #1;T$,No,Nv
910     READ #1;Vn$(*),Ns
920     READ #1;Sn$(*),Sc(*)
930     REDIM Elevs_temp(No,Nv)
940     MAT READ #1;Elevs_temp
950     FOR I=1 TO 301
960       Elevations(I,Traverse)=Elevs_temp(I,1)
970     NEXT I
980     MAT SEARCH Elevs_temp(*,1),MAX;Max_elev_temp
990     MAT SEARCH Elevs_temp(*,1),MIN;Min_elev_temp
1000    IF Min_elev>Min_elev_temp THEN Min_elev=Min_elev_temp
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
1010     IF Max_elev<Max_elev_temp THEN Max_elev=Max_elev_temp
1020   NEXT Traverse
1030   Min_elev=INT(Min_elev/100)*100
1040   Max_elev=INT((Max_elev+100)/100)*100
1050   Plot_on=1
1060   INPUT "WHERE SHALL I PLOT THE FIGURE? (1=CRT,2=9872A)",Plot_on
1070   CALL Plot_setup(A(*),Plot_on,Min_elev,Max_elev)
1080   CALL Plot_points(Quad,Elevations(*),Names$(*),Letter$(*),Min_elev,Max_elev
,Plot_on,Check$,K,Contour_int)
1090   IF Plot_on=2 THEN
1100     PEN 0
1110     MOVE 5,5
1120   END IF
1130   CALL Beeper(3,5)
1140   PAUSE
1150   EXIT GRAPHICS
1160   GOTO More_plots
1170   END
1180   ! ***********************************************************************
1190   ! *                                                                     *
1200   ! *      CREATES THE BASIC CROSS SECTION PLOT                           *
1210   ! *      GSTORES THIS PLOT FOR FURTHER USE.                             *
1220   ! *                                                                     *
1230   ! ***********************************************************************
1240   SUB Plot_setup(INTEGER A(*),REAL Plot_on,Min_elev,Max_elev)
1250     OPTION BASE 1
1260     DEG
1270     Line_length=.5
1280     Max_x=134.47
1290     Max_y=149.8
1300     SELECT Plot_on
```

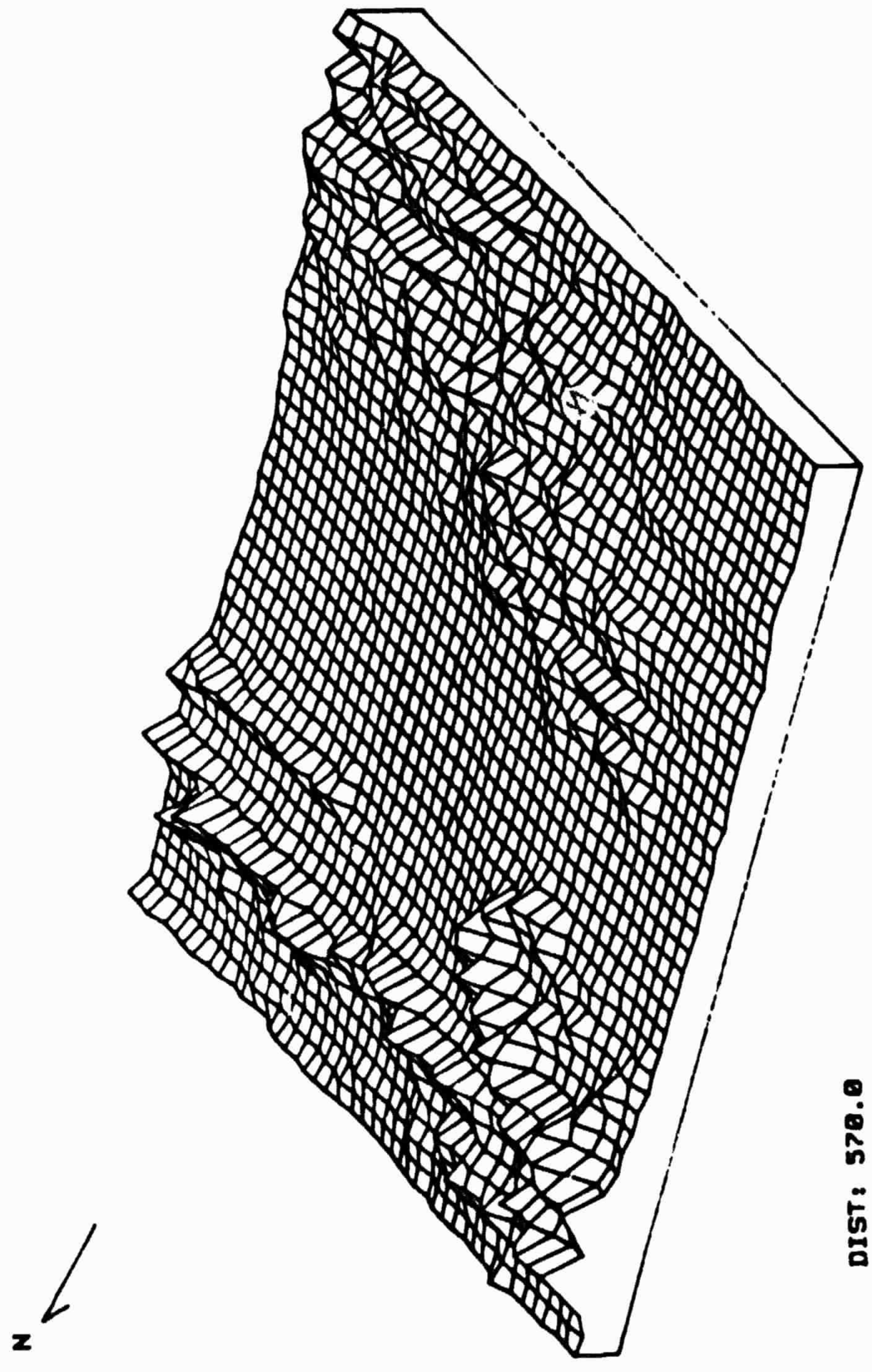
```
1310     CASE 2
1320       Line_length=4
1330       PLOTTER IS "9872A"
1340       Mm=25.4
1350       Max_x=279.4
1360       Max_y=215.9
1370       PRINTER IS 7
1380       PRINT "VS 5"
1390       PRINTER IS 16
1400     CASE 3
1410       PLOTTER IS "GRAPHICS"
1420       GRAPHICS
1430     END SELFCT
1440     LIMIT 0,Max_x,0,Max_y
1450     Mult_x=Max_x/279.4
1460     Mult_y=Max_y/215.9
1470     LOCATE RATIO*100*60*Mult_x/Max_x,RATIO*100*250*Mult_x/Max_x,100*40*Mult_
y/Max_y,100*200*Mult_y/Max_y
1480     SCALE 0,301,Min_elev,Max_elev
1490     UNCLIP
1500     LORG 5
1510     PEN 1
1520     CLIP 1,301,Min_elev,Max_elev
1530     Increment=1000
1540     IF Max_elev-Min_elev<2000 THEN Increment=500
1550     IF Max_elev-Min_elev<800 THEN Increment=100
1560     AXES 50,Increment,1,Min_elev,2,1
1570     IF Plot_on=2 THEN
1580       PRINTER IS 7
1590       PRINT "VS 36"
1600       PRINTER IS 16
```

```
1610    END IF
1620    UNCLIP
1630    FOR I=0 TO 300 STEP 100
1640      MOVE I,Min_elev+(Min_elev-Max_elev)/20
1650      LABEL USING "K";I
1660    NEXT I
1670    LORG 8
1680    FOR I=Min_elev TO Max_elev STEP Increment
1690      MOVE -20,I
1700      LABEL USING "K";I
1710    NEXT I
1720  SUBEND
1730  ! ************************************************************************
1740  ! *                                                                      *
1750  ! *     PRINTS OUT A TABLE WITH THE NAMES OF EACH AVAILABLE              *
1760  ! *     QUAD. NAMES ARE PRINTED IN ORDER OF QUAD NAMES OR                *
1770  ! *     STATES AS DESIRED.                                               *
1780  ! *                                                                      *
1790  ! ************************************************************************
1800  SUB Quad_name_table(Names$(*),Name_order(*),State_order(*),Names_order(*))
1810    OPTION BASE 1
1820    MAT Names_order=Name_order
1830    List_order=1
1840    INPUT "DO YOU WANT QUADS LISTED IN ORDER OF (1=NAMES, 2=STATES)?",List_o
rder
1850    IF List_order=2 THEN MAT Names_order=State_order
1860    Print_unit=16
1870    INPUT "WHERE WOULD YOU LIKE THE LIST PRINTED? (0=THERMAL, 16=CRT)",Print
_unit
1880    PRINTER IS Print_unit
1890    PRINT PAGE
1900    PRINT USING "K";CHR$(226)&RPT$(CHR$(228),78)&CHR$(229)
```

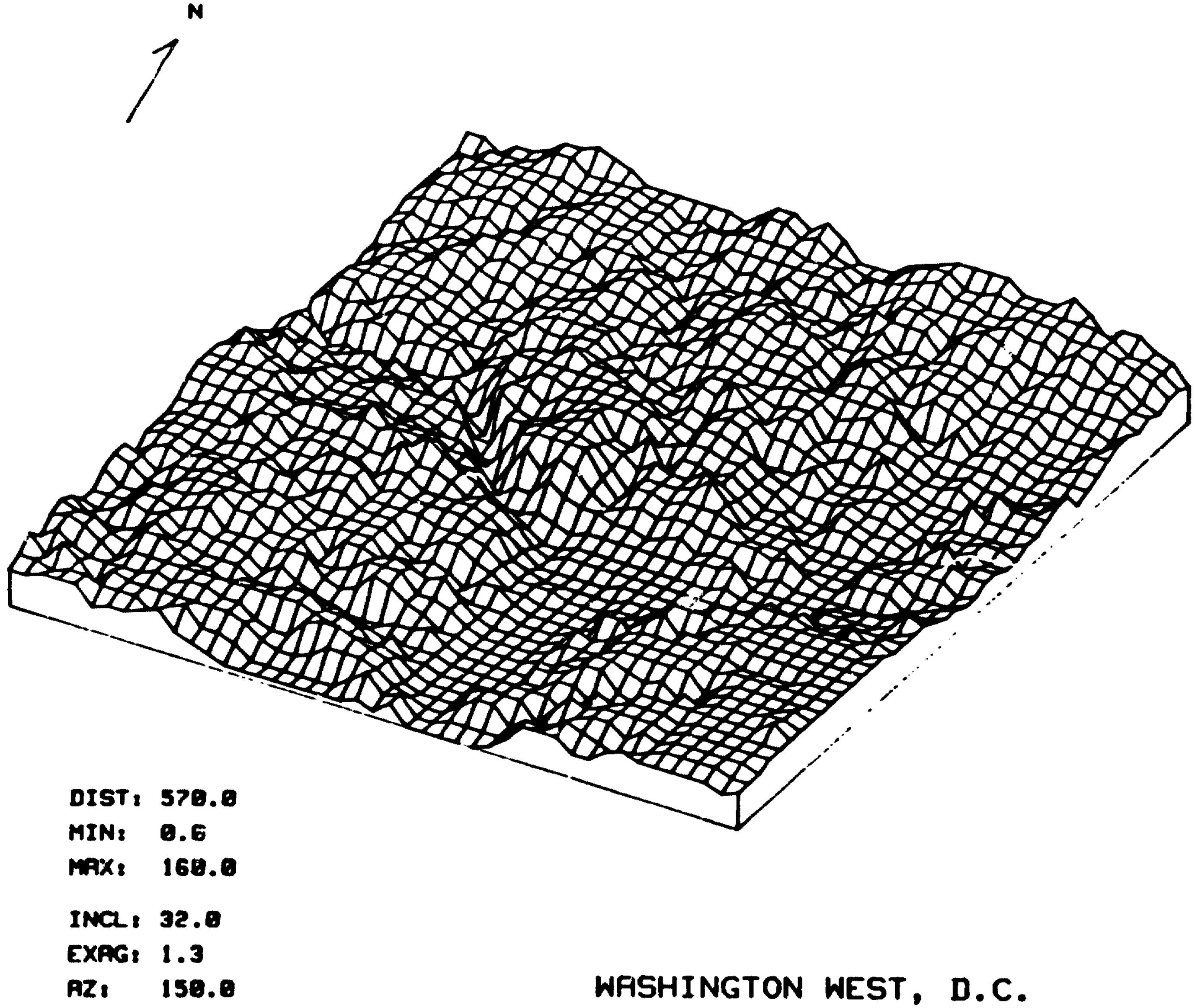
```
1910    PRINT CHR$(231);TAB(26);"QUADRANGLES AVAILABLE FOR STUDY";TAB(80);CHR$(2
31)
1920    PRINT USING "K";CHR$(225)&RPT$(CHR$(228),26)&CHR$(254)&RPT$(CHR$(228),25
)&CHR$(254)&RPT$(CHR$(228),25)&CHR$(230)
1930    FOR Rr=1 TO 17
1940      PRINT CHR$(231);TAB(2);Rr;TAB(6);Names$(Names_order(Rr));TAB(28);"|";T
AB(29);Rr+17;TAB(33);Names$(Names_order(Rr+17));
1950      PRINT TAB(54);"|";TAB(55);Rr+34;TAB(59);Names$(Names_order(Rr+34));TAB
(80);CHR$(231)
1960    NEXT Rr
1970    PRINT USING "K";CHR$(250)&RPT$(CHR$(228),26)&CHR$(249)&RPT$(CHR$(228),25
)&CHR$(249)&RPT$(CHR$(228),25)&CHR$(253)
1980    PRINTER IS 16
1990  SUBEND
2000  ! *********************************************************************
2010  ! *                                                                   *
2020  ! *      TESTS IF CORRECT DISK IS IN DRIVE.                           *
2030  ! *                                                                   *
2040  ! *********************************************************************
2050  SUB No_disk
2060    PRINTER IS 16
2070    PRINT PAGE
2080    PRINT "PUT DISK IN DRIVE AND RESTART PROGRAM"
2090    OFF ERROR
2100    STOP
2110  SUBEND
2120  ! *********************************************************************
2130  ! *                                                                   *
2140  ! *    WHEN CORRECT DISK IS NOT IN DRIVE.                             *
2150  ! *                                                                   *
2160  ! *********************************************************************
2170  SUB No_file(Return_var)
2180    PRINTER IS 16
2190    PRINT PAGE
2200    PRINT "PUT CORRECT DISK IN DRIVE AND RESTART PROGRAM"
```

```
2210    STOP
2220  SUBEND
2230  ! ***********************************************************************
2240  ! *                                                                     *
2250  ! *    WHAT DO YOU THINK THIS DOES DUMMY!                               *
2260  ! *                                                                     *
2270  ! ***********************************************************************
2280  SUB Beeper(N_times,Hundredths)
2290    FOR I=1 TO N_times
2300      BEEP
2310      WAIT 100*Hundredths
2320    NEXT I
2330  SUBEND
2340  ! ***********************************************************************
2350  ! *                                                                     *
2360  ! *     PUTS PEN AWAY AND MOVES IT OUT OF THE WAY.                      *
2370  ! *                                                                     *
2380  ! ***********************************************************************
2390  SUB Endplots
2400    PENUP
2410    PEN 0
2420    MOVE 99,99
2430    CALL Beeper(4,5)
2440    STOP
2450  SUBEND
2460  ! ***********************************************************************
2470  ! *                                                                     *
2480  ! *      PLOTS THE VALUES OF ELEVATION                                  *
2490  ! *      PLOTS STATISTICS OF FIT FOR THE FOUR TRAVERSES.                *
2500  ! *                                                                     *
```

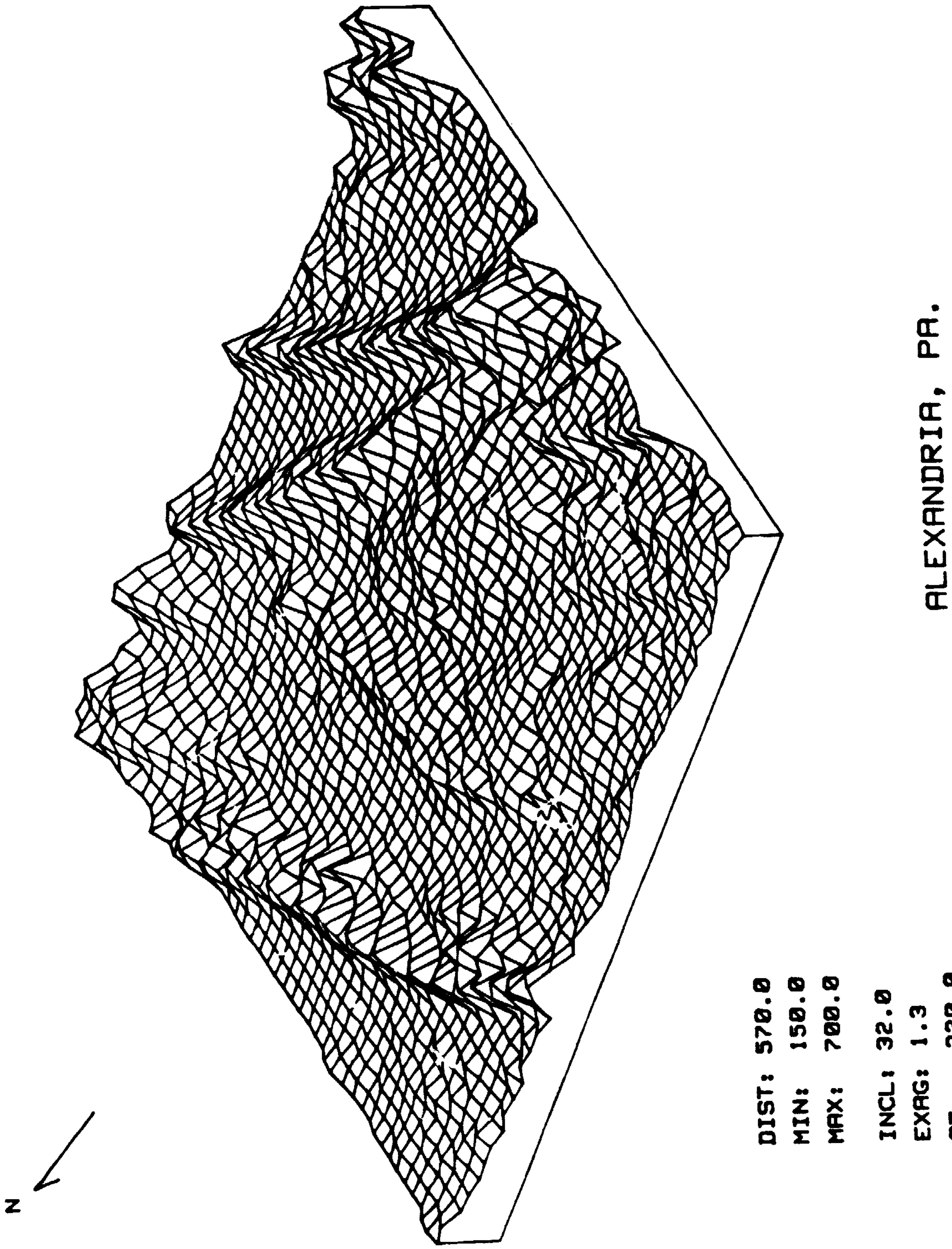
```
2510  ! ************************************************************************
2520  SUB Plot_points(Quad,Elevations(*),Names$(*),Letter$(*),Min_elev,Max_elev,
Plot_on,Check$,K,Contour_int)
2530    OPTION BASE 1
2540    LORG 5
2550    Begin=1
2560    Endit=301
2570    Up=(Max_elev-Min_elev)/10
2580    MOVE 200,Max_elev-.5*Up
2590    IF Quad THEN LABEL USING "K";Names$(Quad)
2600    FOR Traverse=1 TO 4
2610      PEN Traverse
2620      IF Plot_on=1 THEN LINE TYPE 3+Traverse,.3
2630      MOVE 1,Elevations(1,Traverse)
2640      FOR I=Begin TO Endit
2650        DRAW I,Elevations(I,Traverse)
2660        IF Check$="Y" THEN
2670          IF (I>1) AND (I<Endit) THEN
2680            IF SGN(Elevations(I-1,Traverse)-Elevations(I,Traverse))<>SGN(Ele
vations(I,Traverse)-Elevations(I+1,Traverse)) THEN
2690              IF SGN(Elevations(I-1,Traverse)-Elevations(I+1,Traverse))<>0 T
HEN
2700                IF K*ABS(Elevations(I-1,Traverse)-Elevations(I+1,Traverse))<
ABS(Elevations(I-1,Traverse)-Elevations(I,Traverse)) THEN
2710                  IF ABS(Elevations(I-1,Traverse)-Elevations(I,Traverse))>Co
ntour_int THEN
2720                    BEEP
2730                    PENUP
2740                    MOVE I,Elevations(I,Traverse)+Up
2750                    DRAW I,Elevations(I,Traverse)+4*Up
2760                    LABEL USING "K";"*"
2770                    MOVE I,Elevations(I,Traverse)
2780                    PRINT "********************************"
2790                    PRINT I-1,Elevations(I-1,Traverse)
2800                    PRINT I,Elevations(I,Traverse)
```



MENA, AK.



WASHINGTON WEST, D.C.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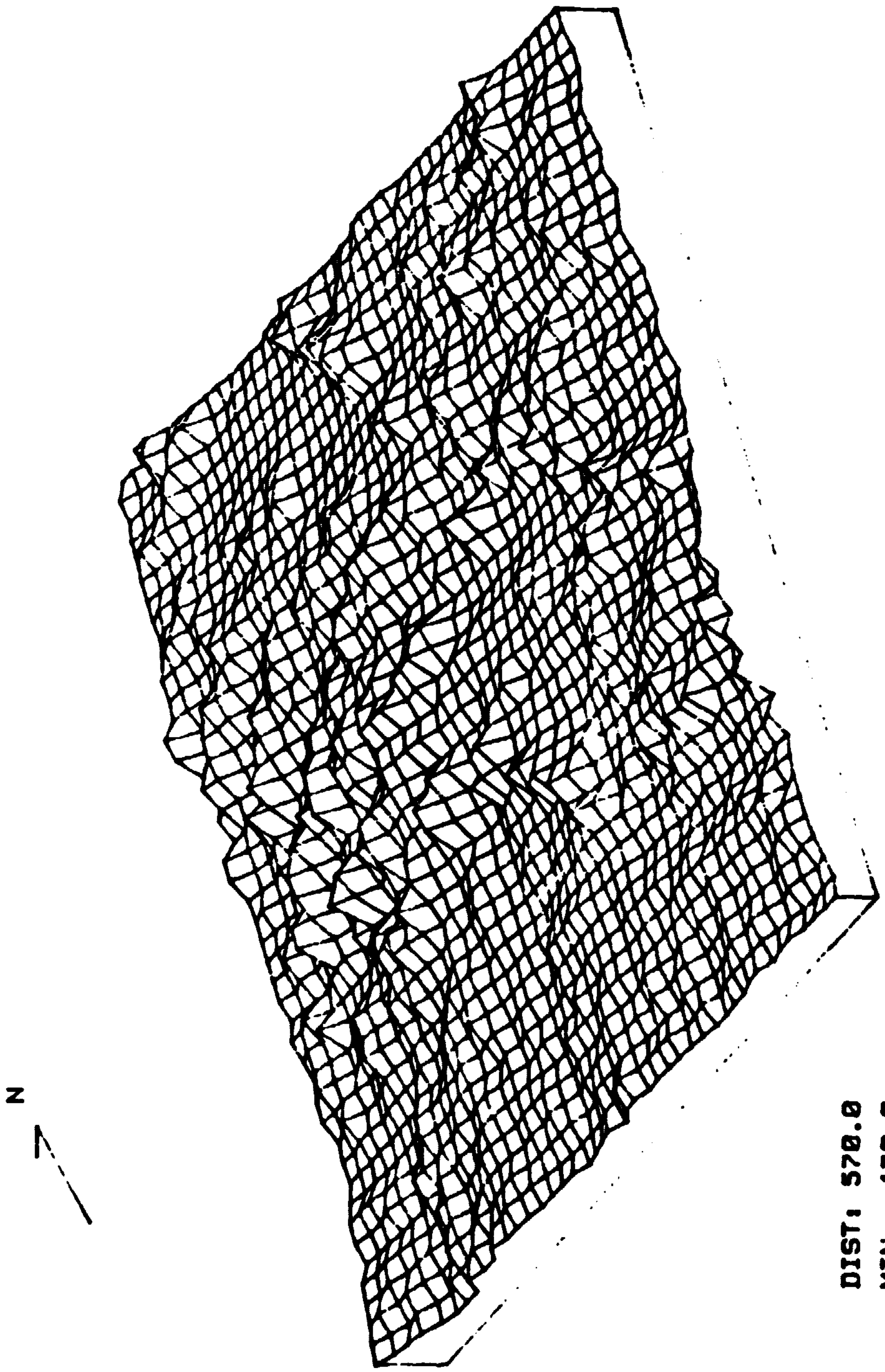
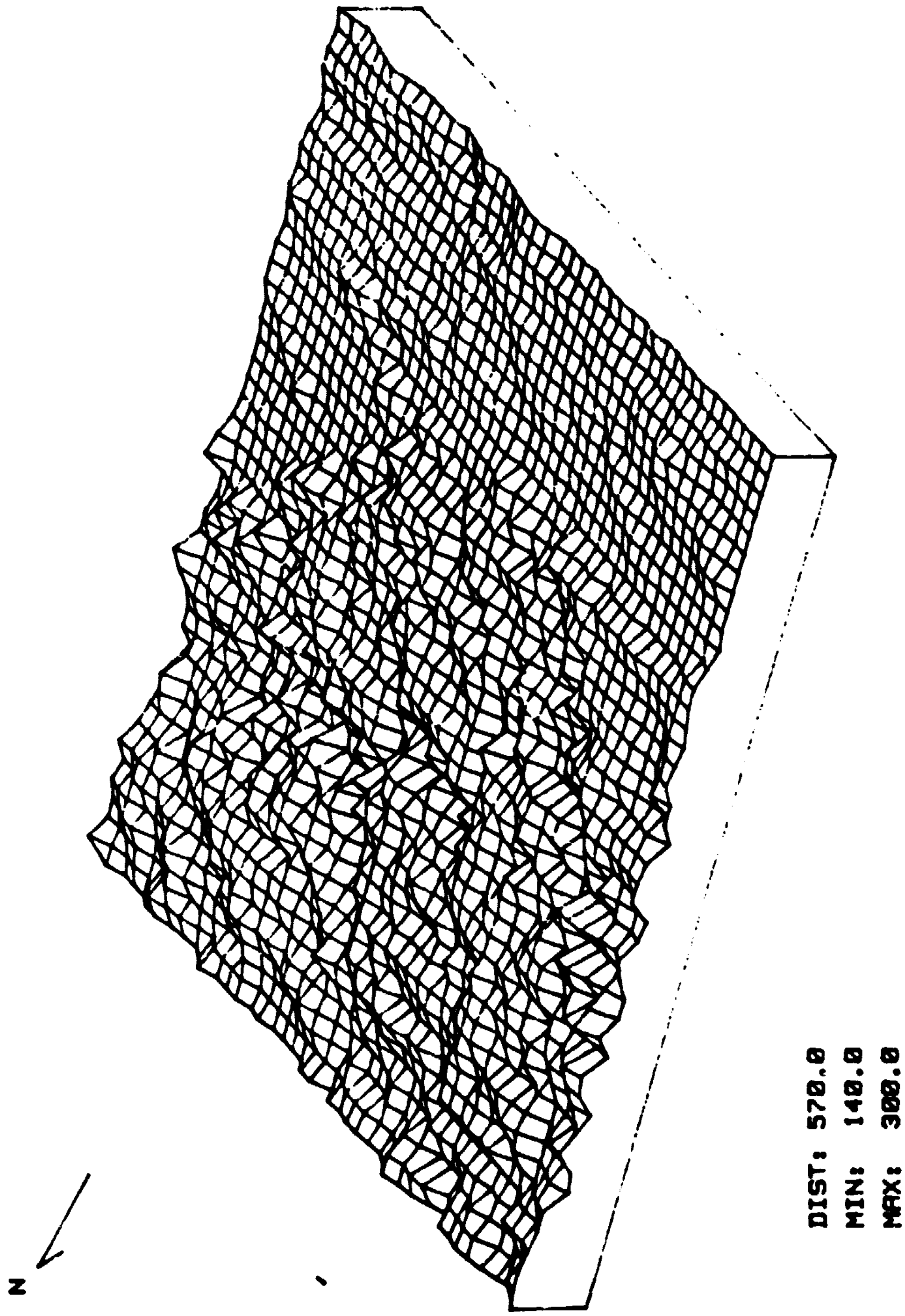
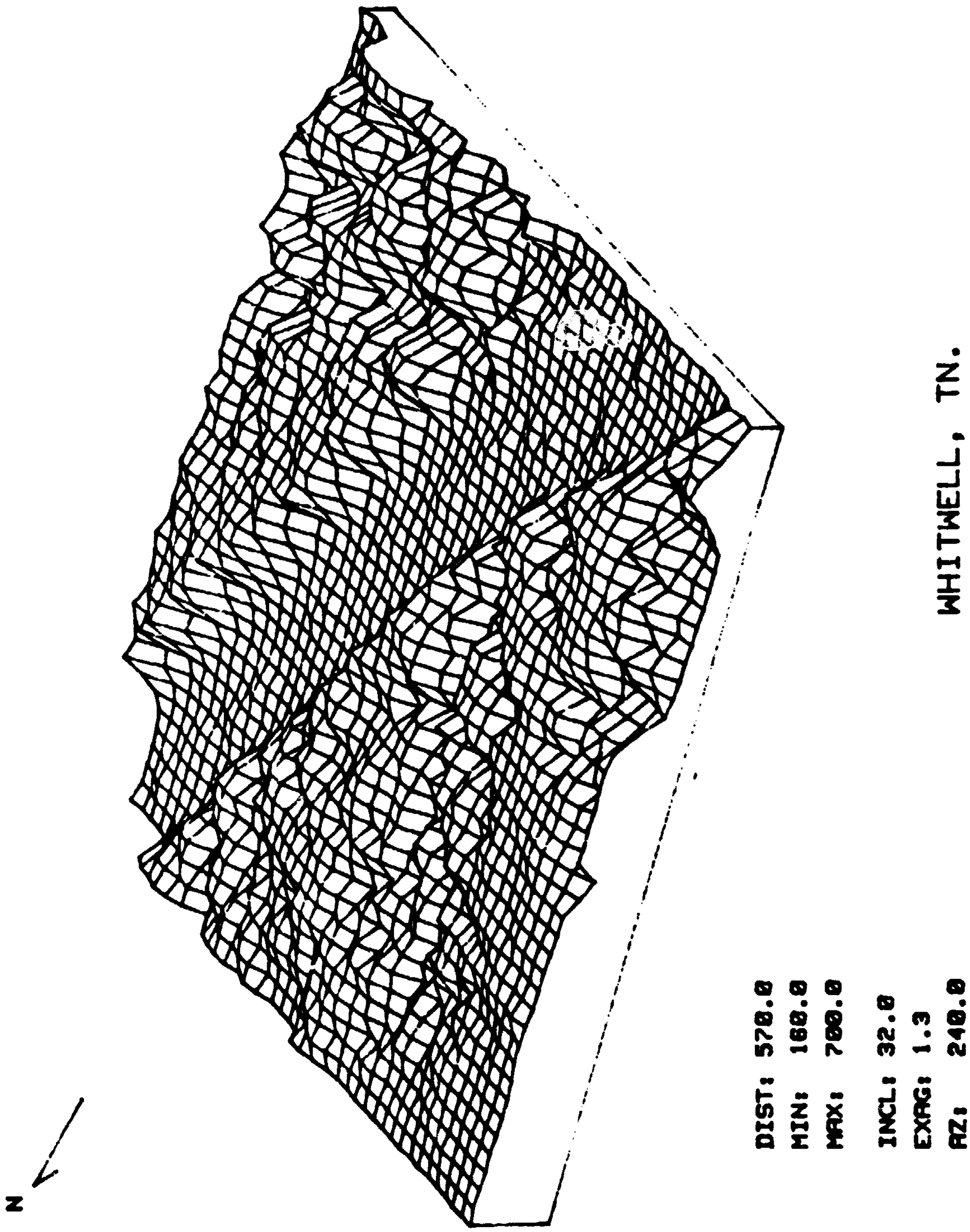


IRONTON, MO.



MAMMOTH CAVE, KY.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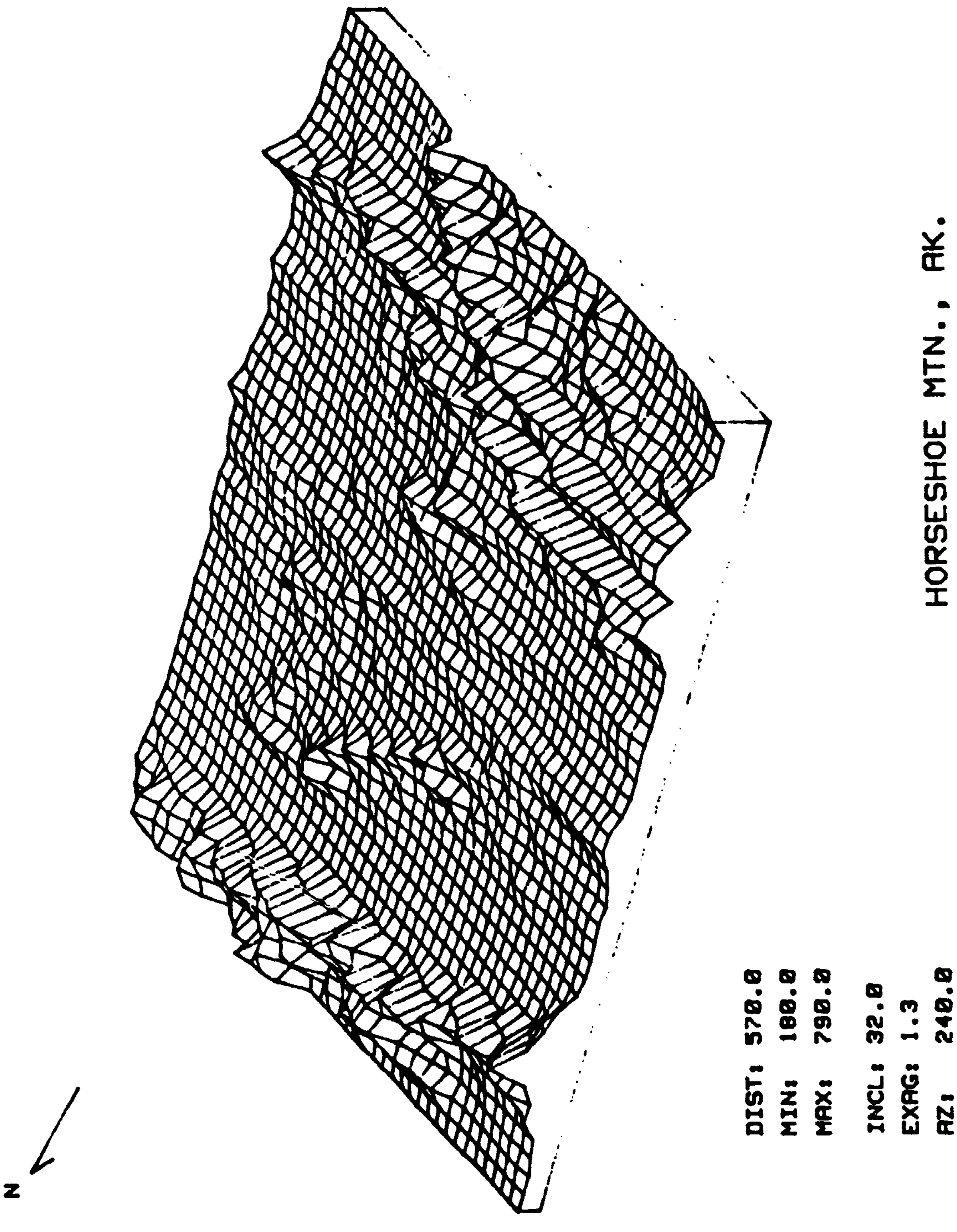

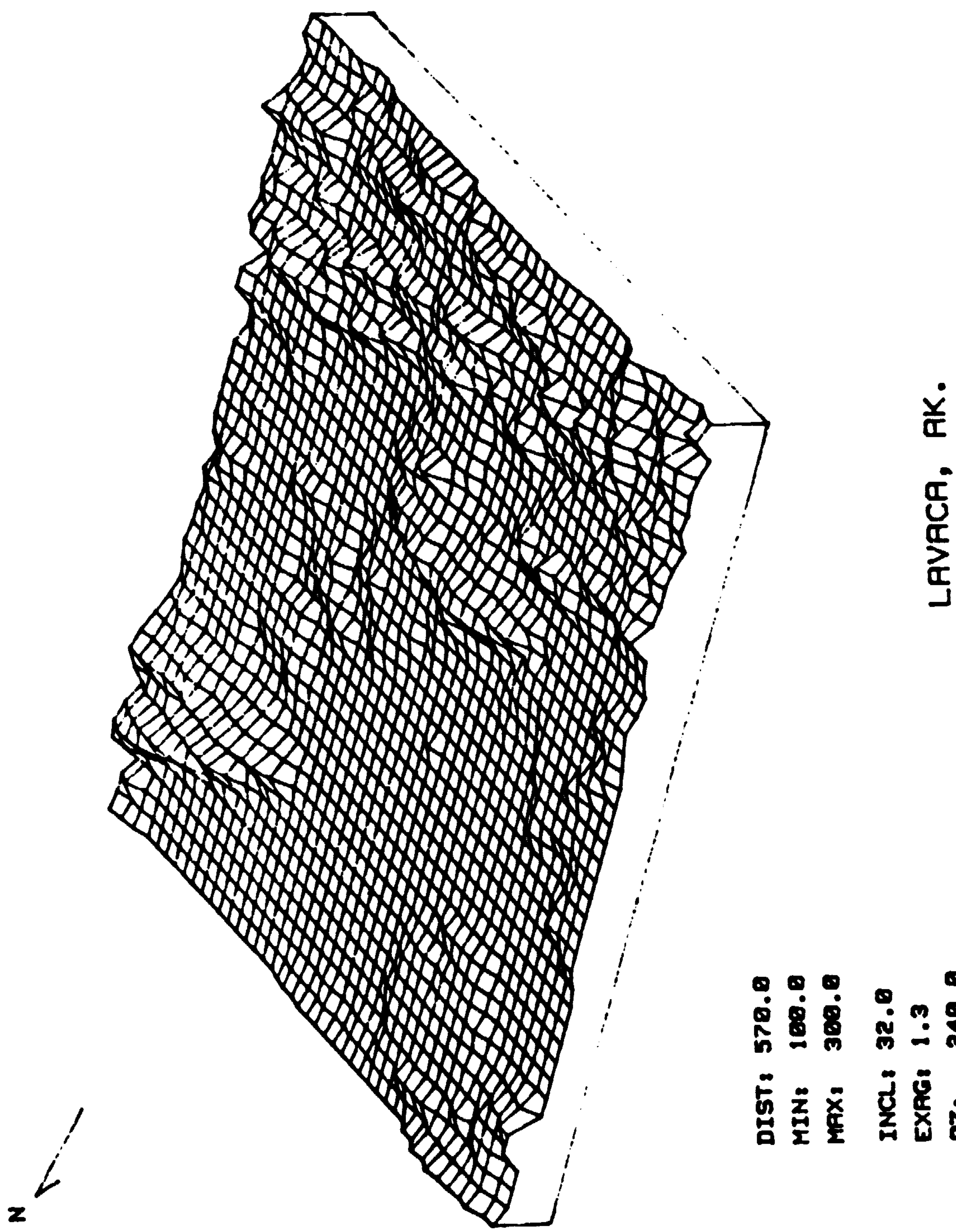
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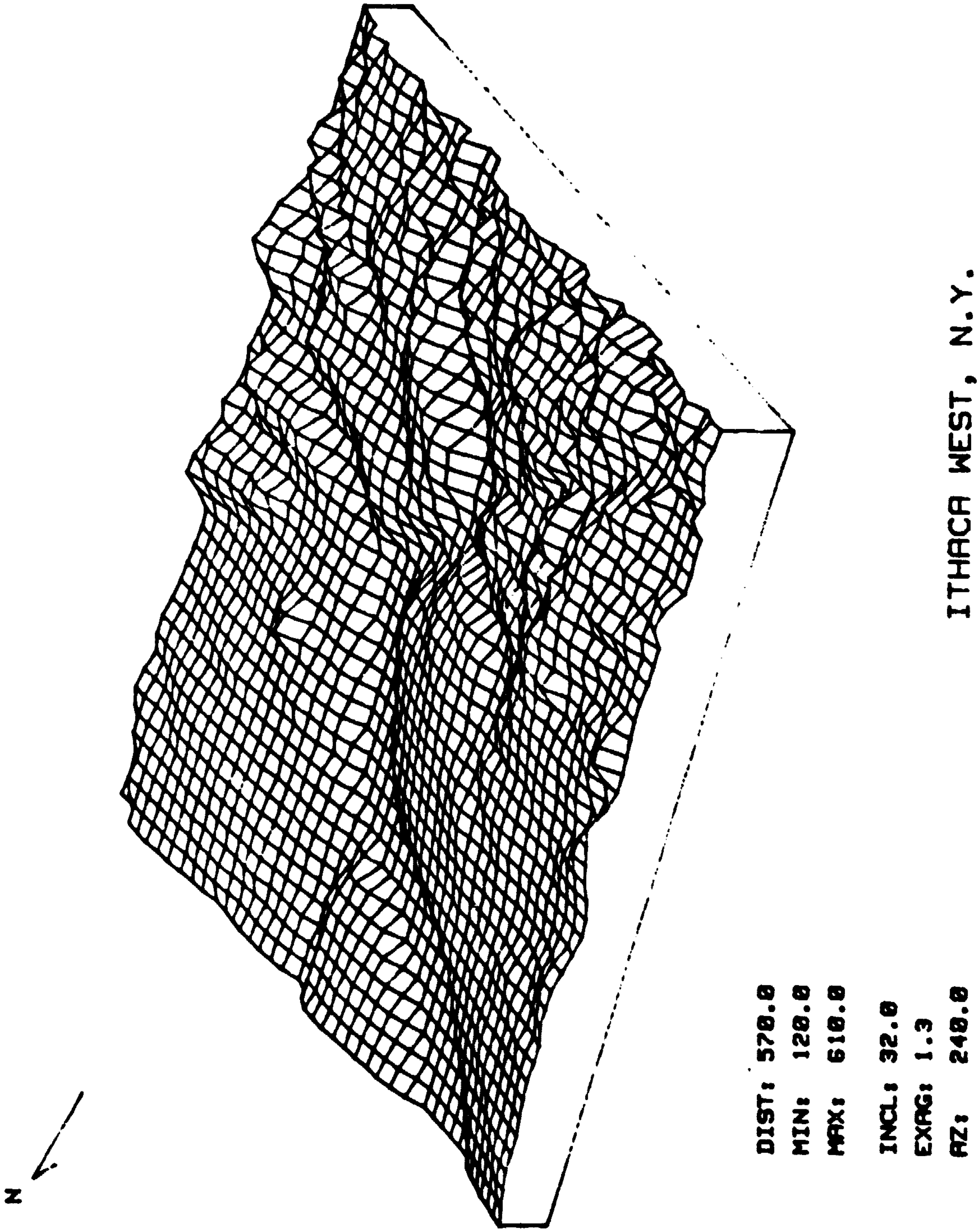
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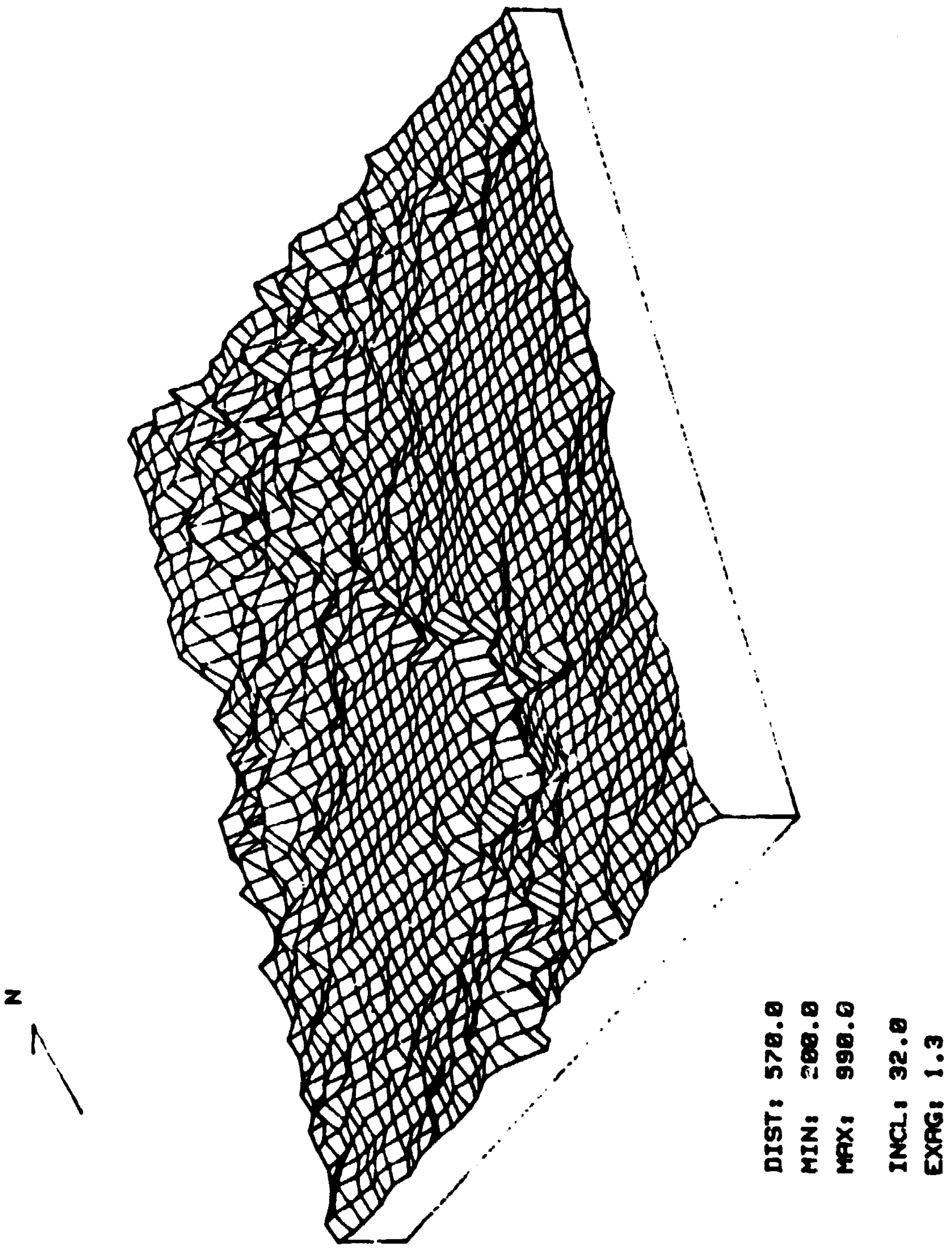

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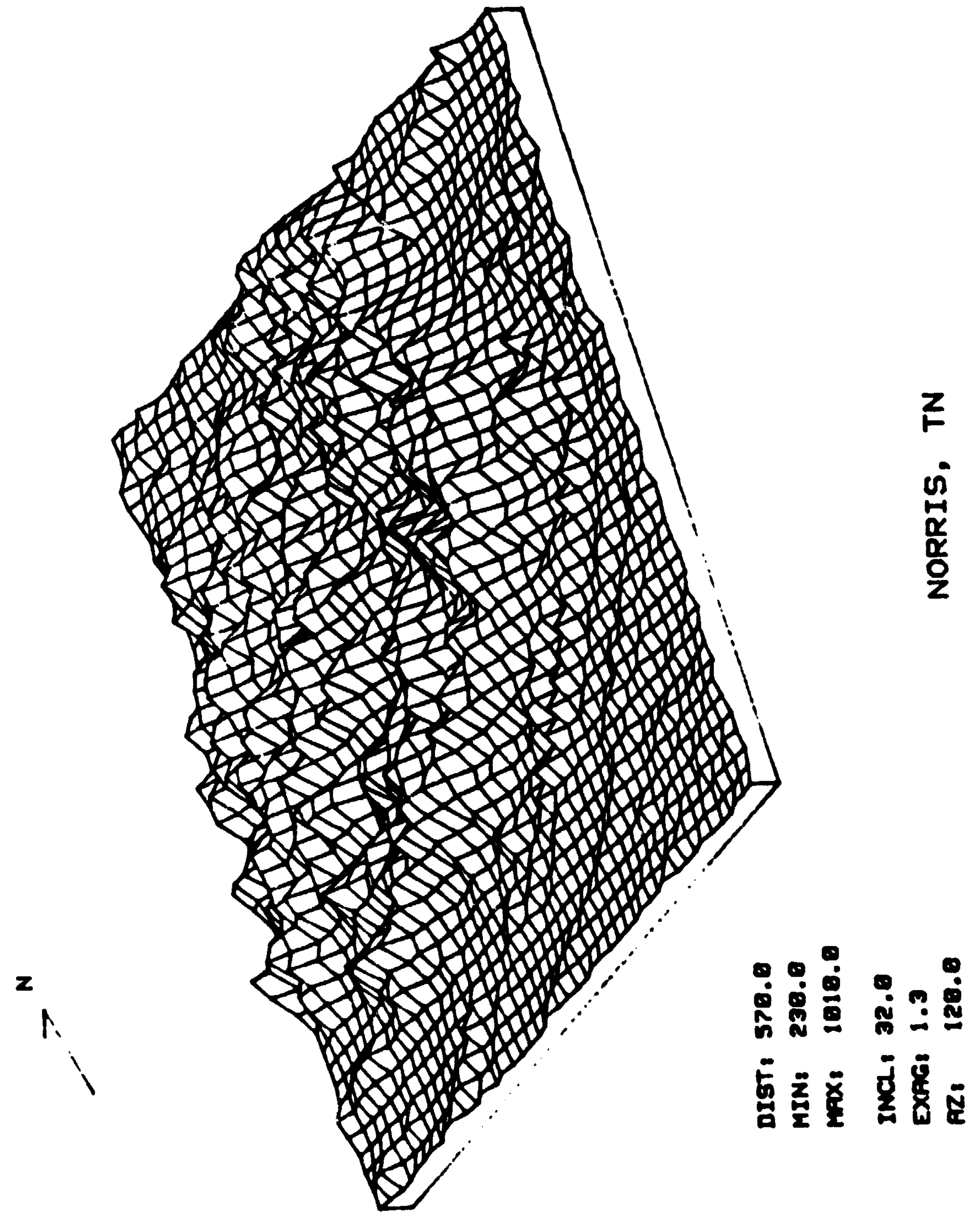
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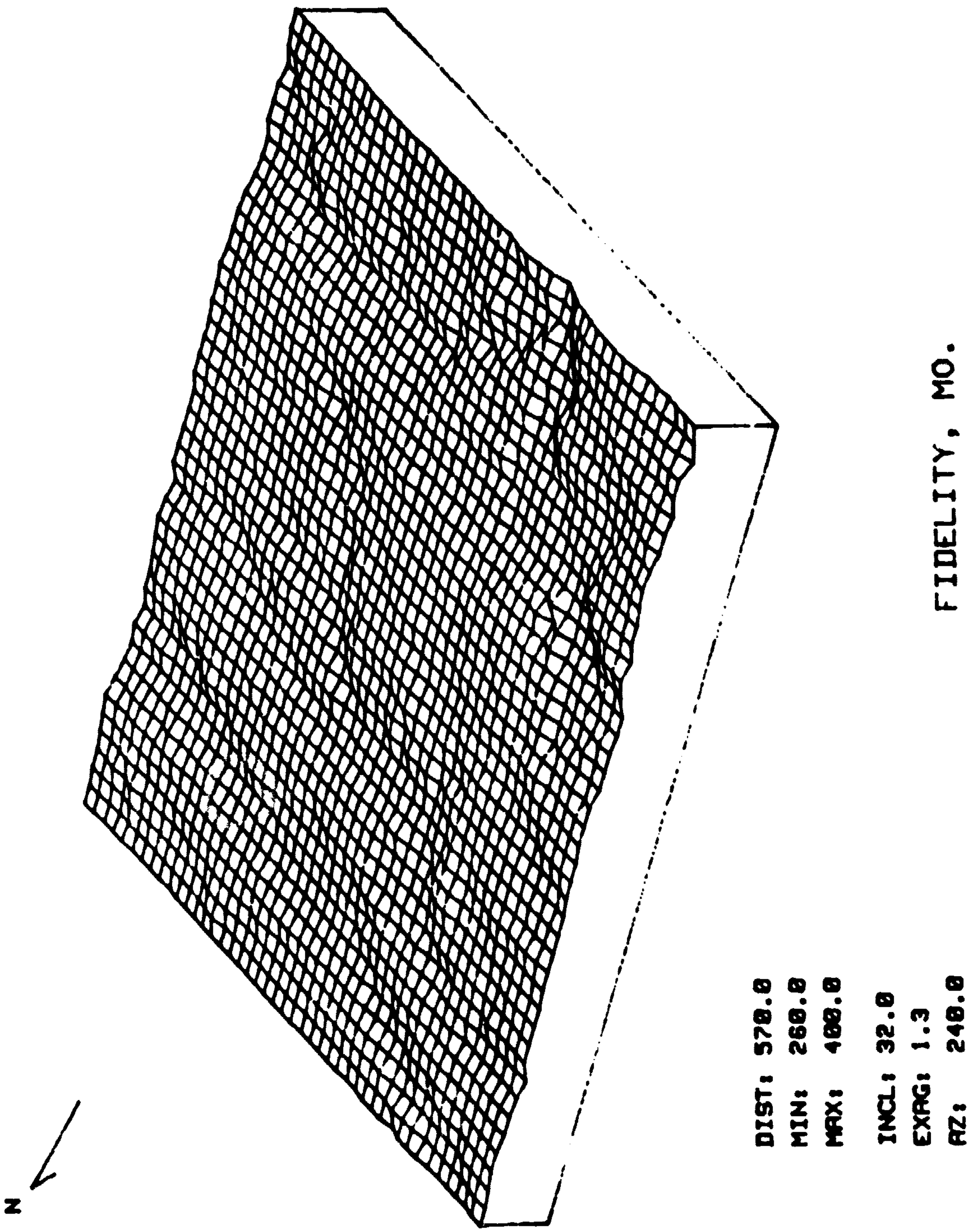
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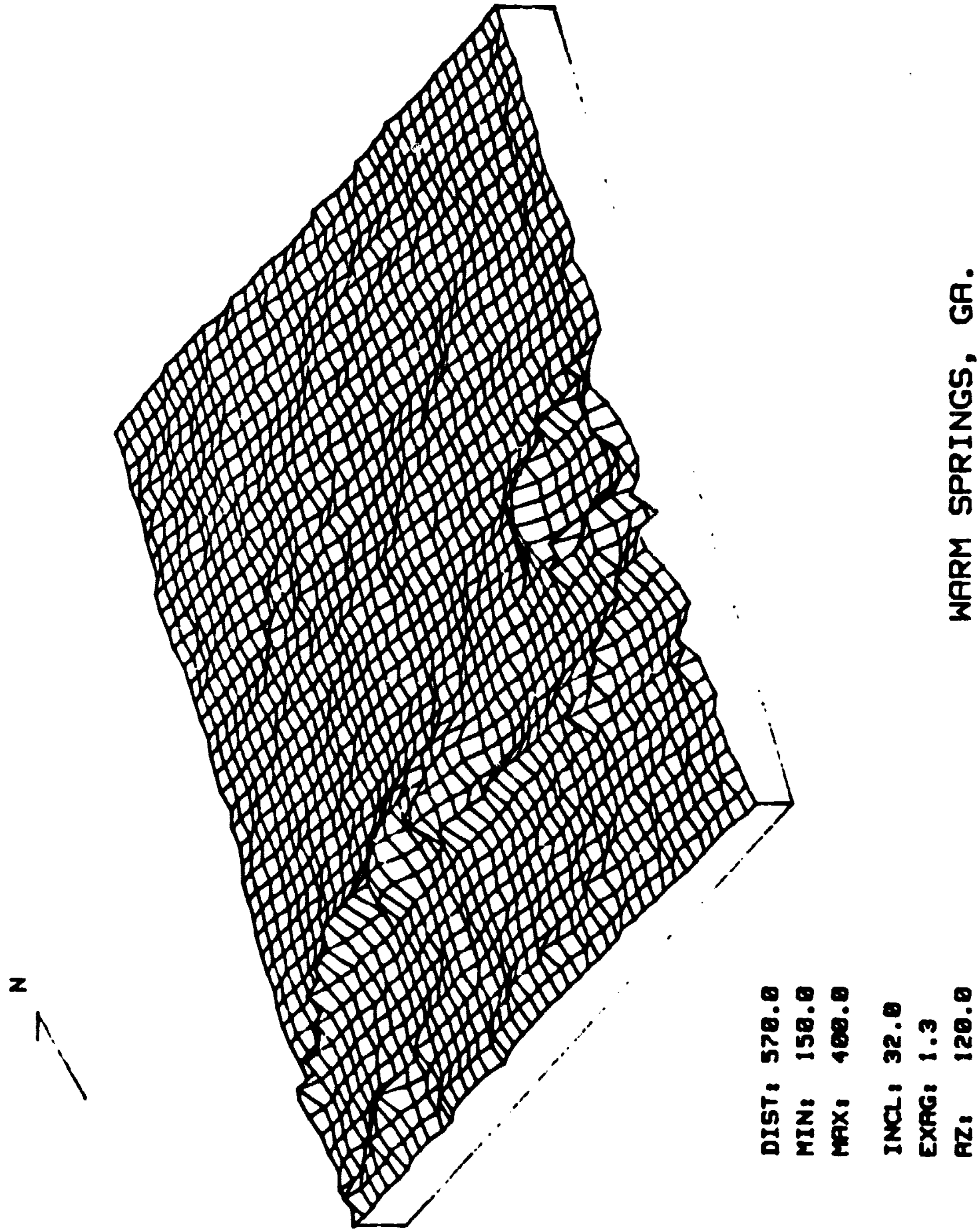
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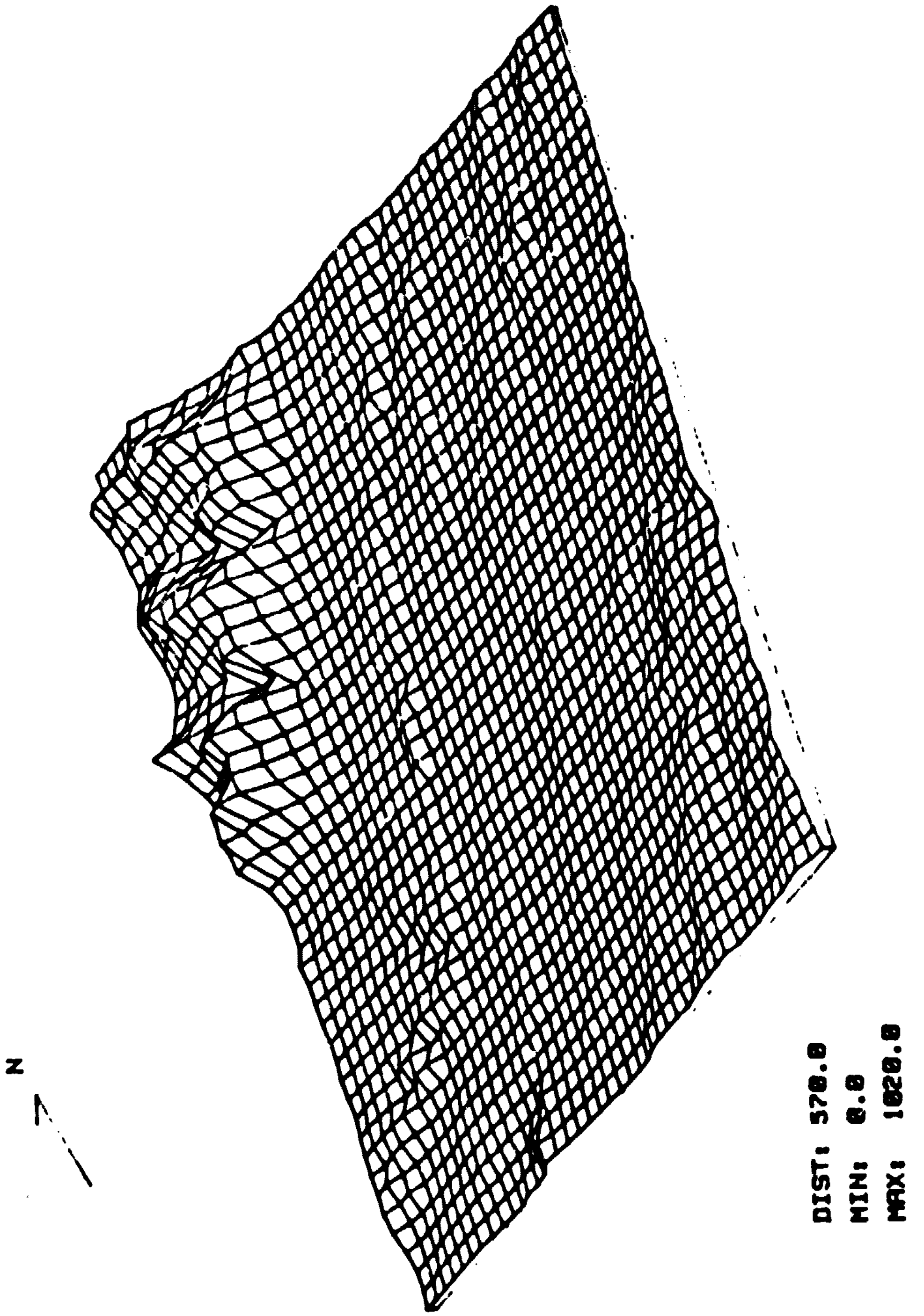
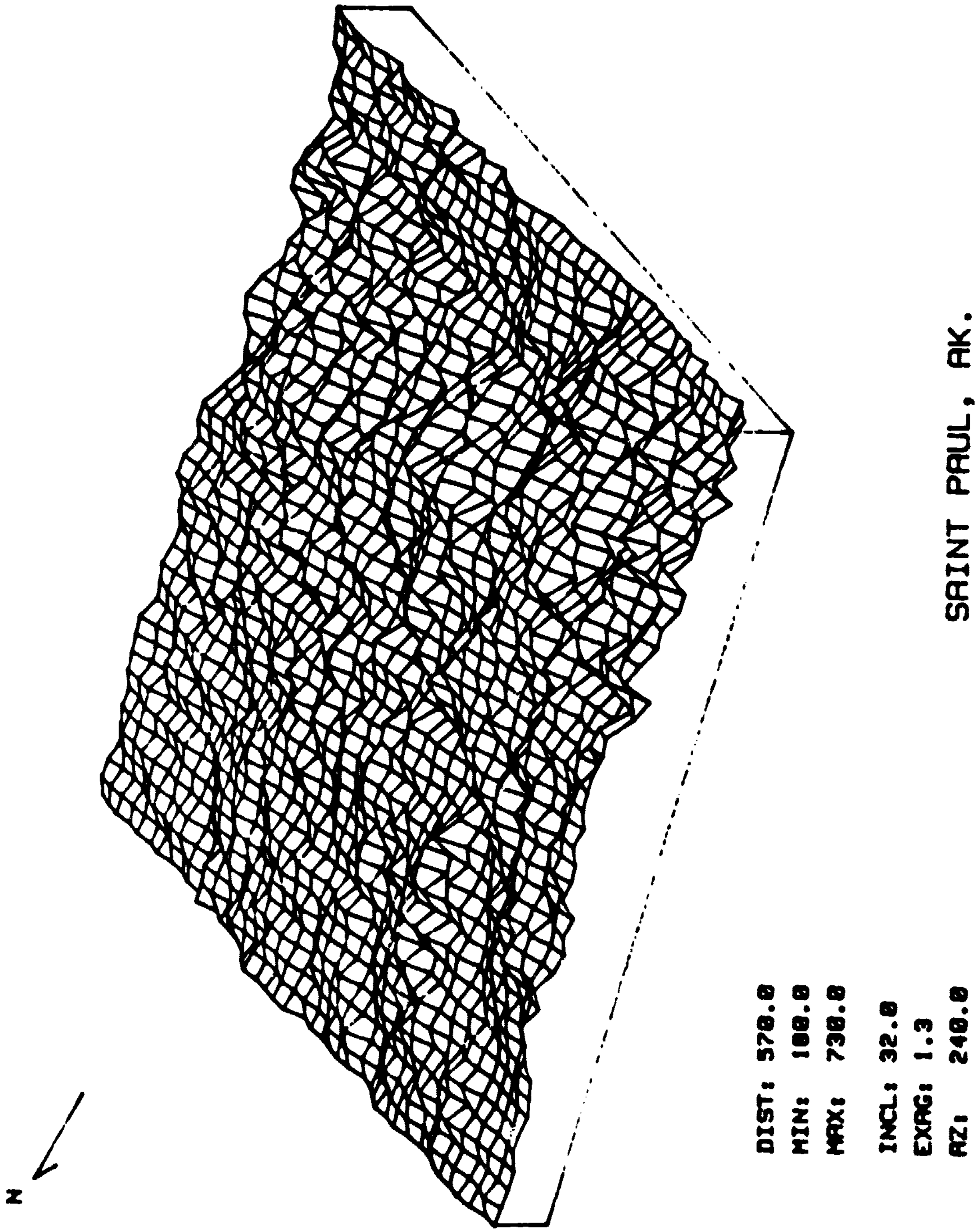


SAUGERTIES, N.Y.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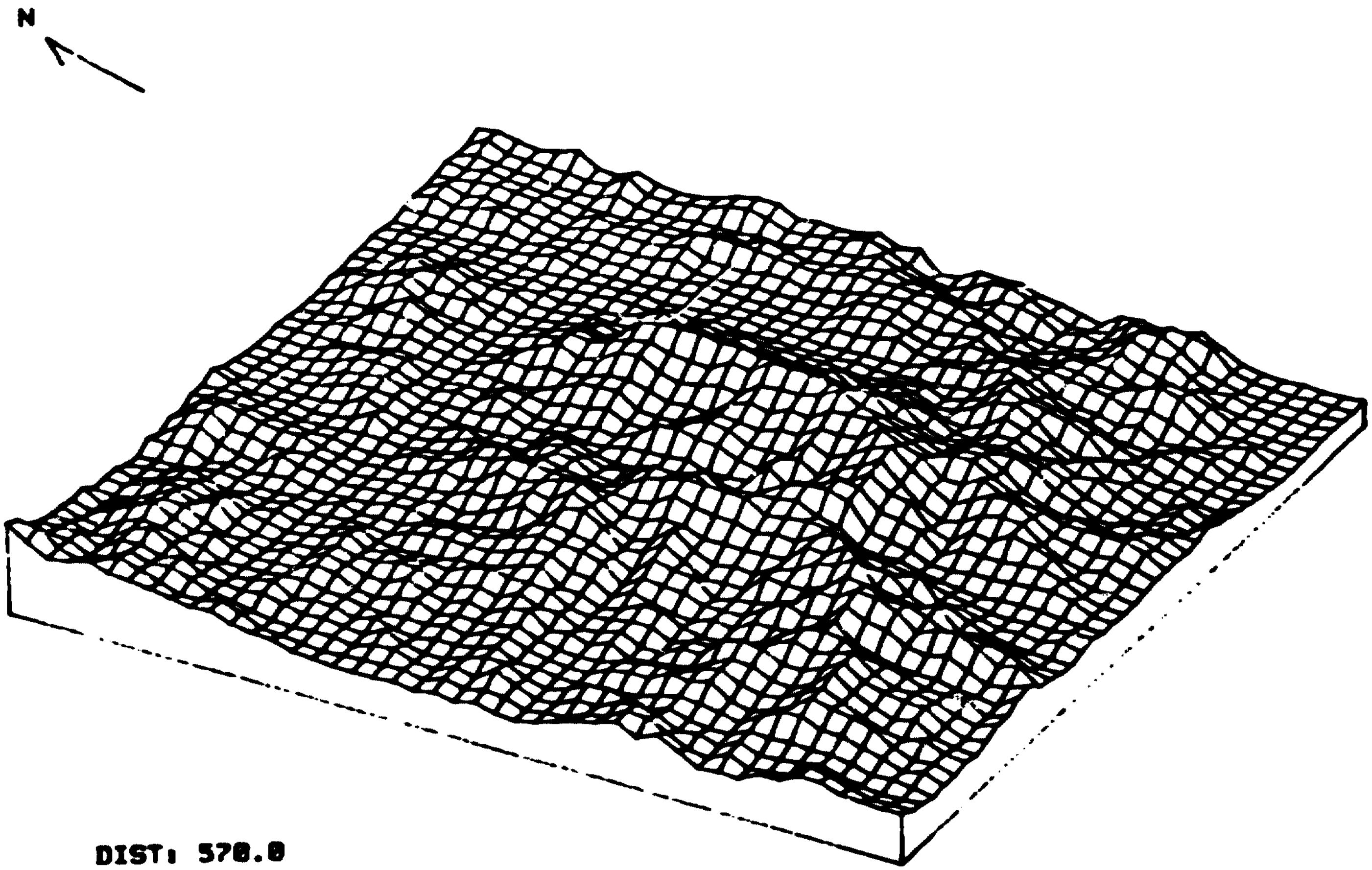
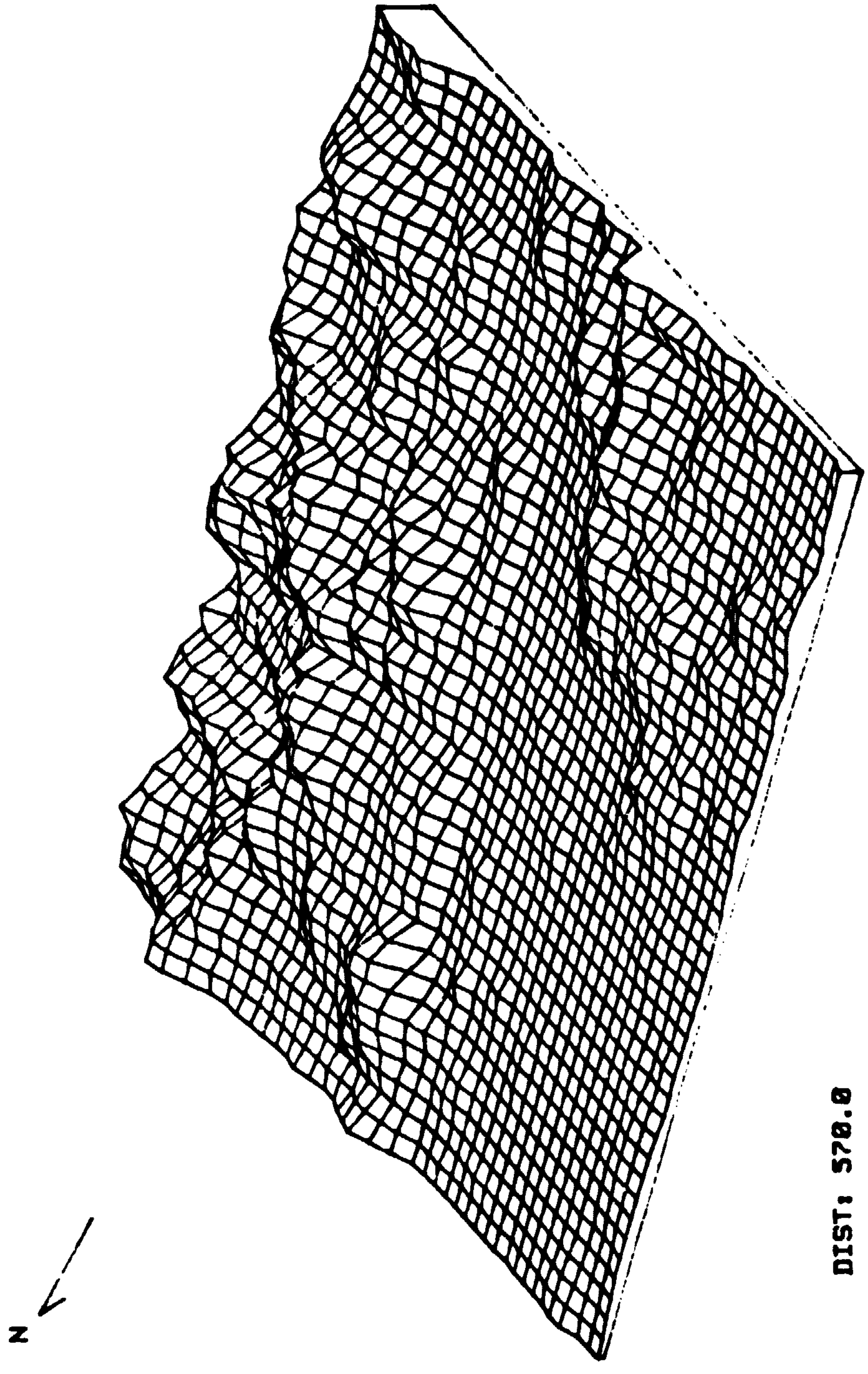


MOUNT MITCHELL, N.C.



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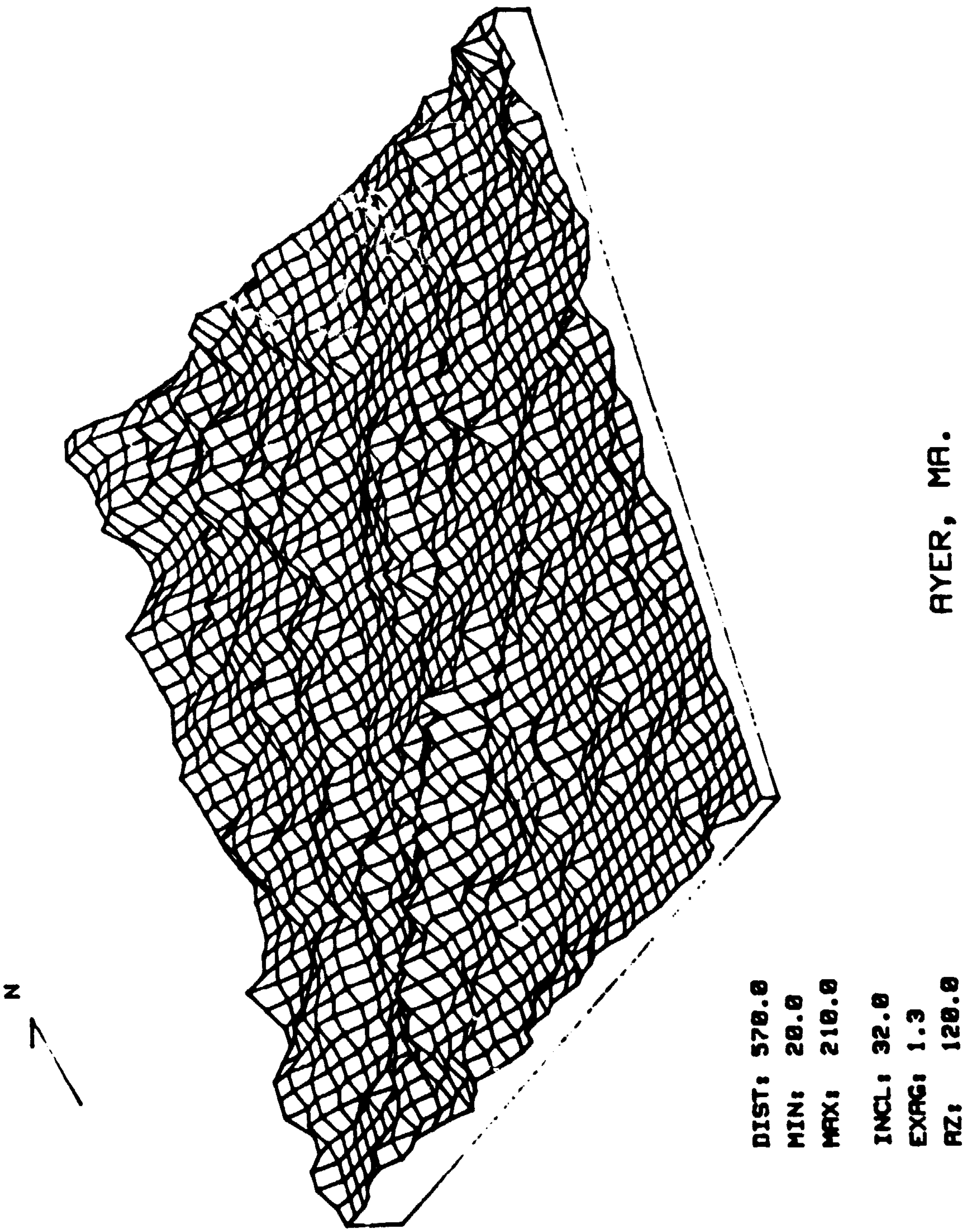
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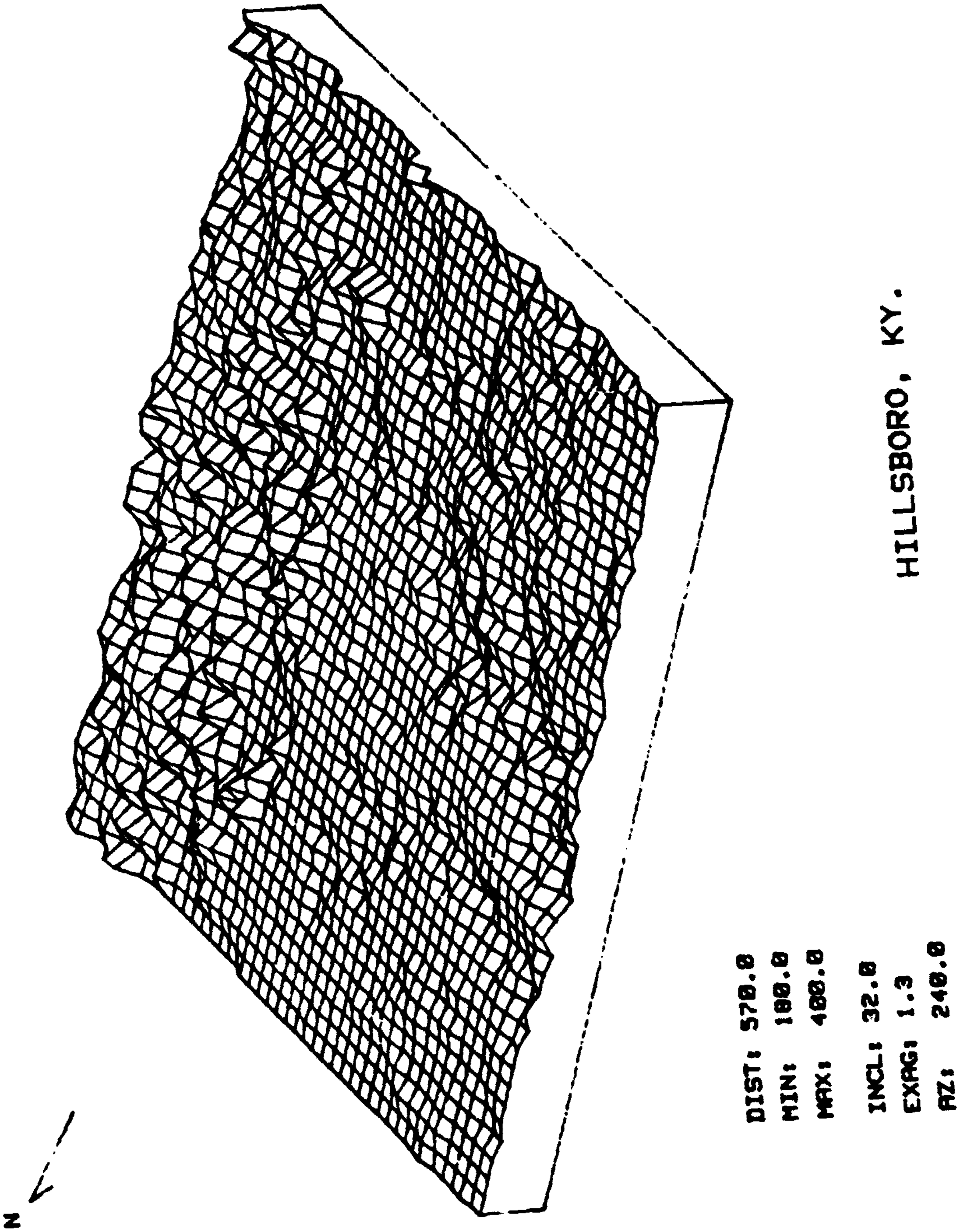
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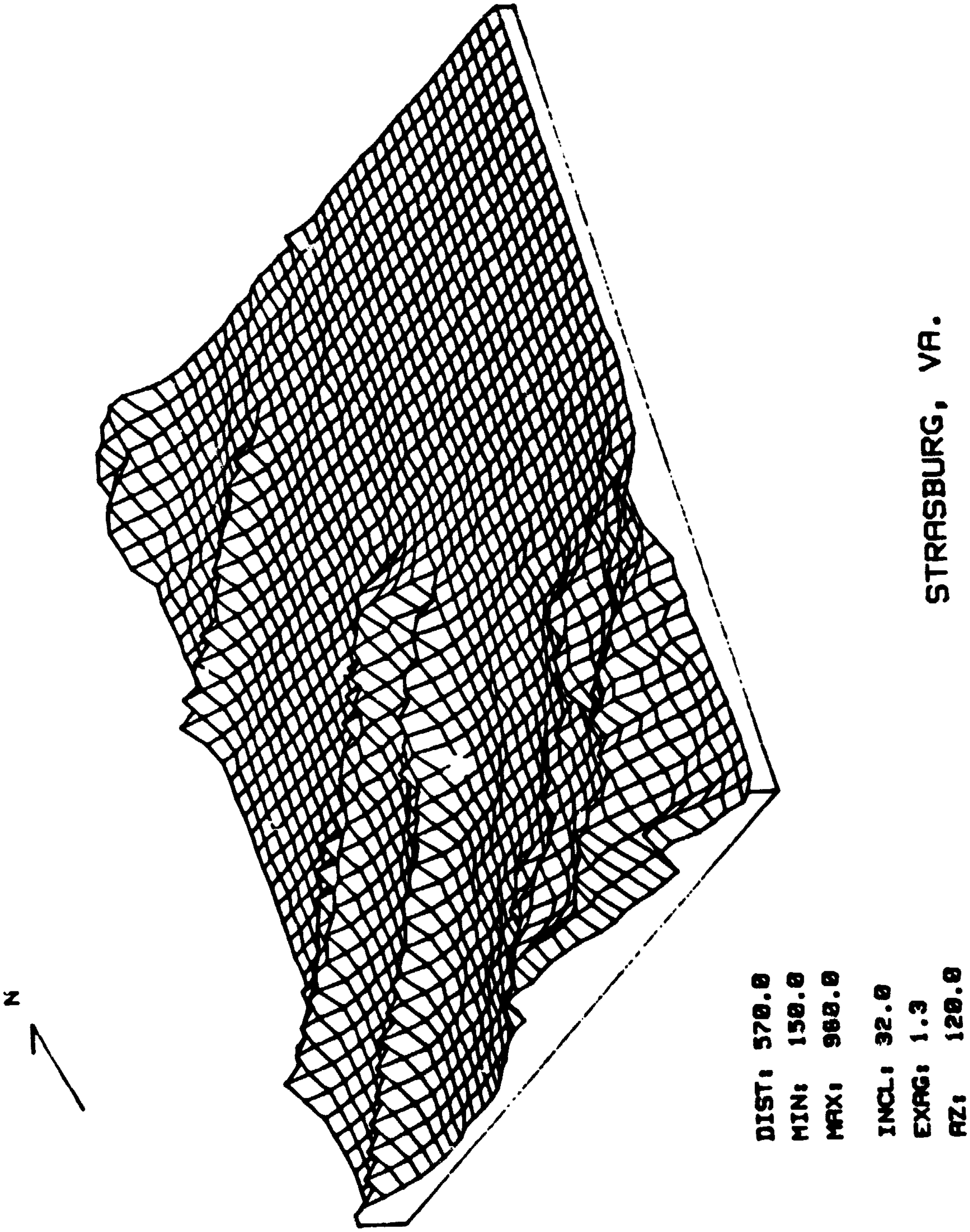
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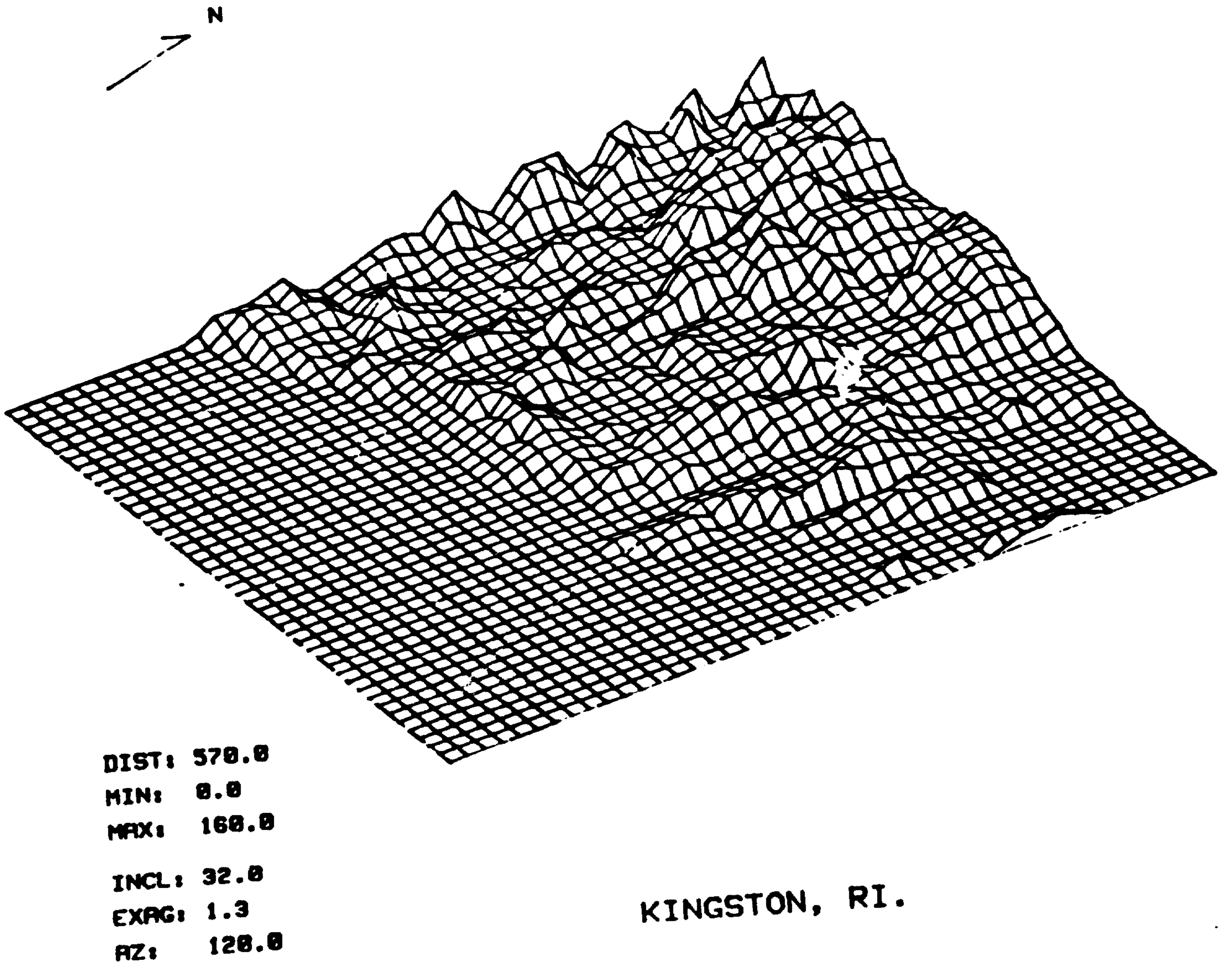

KINGSTON, RI.

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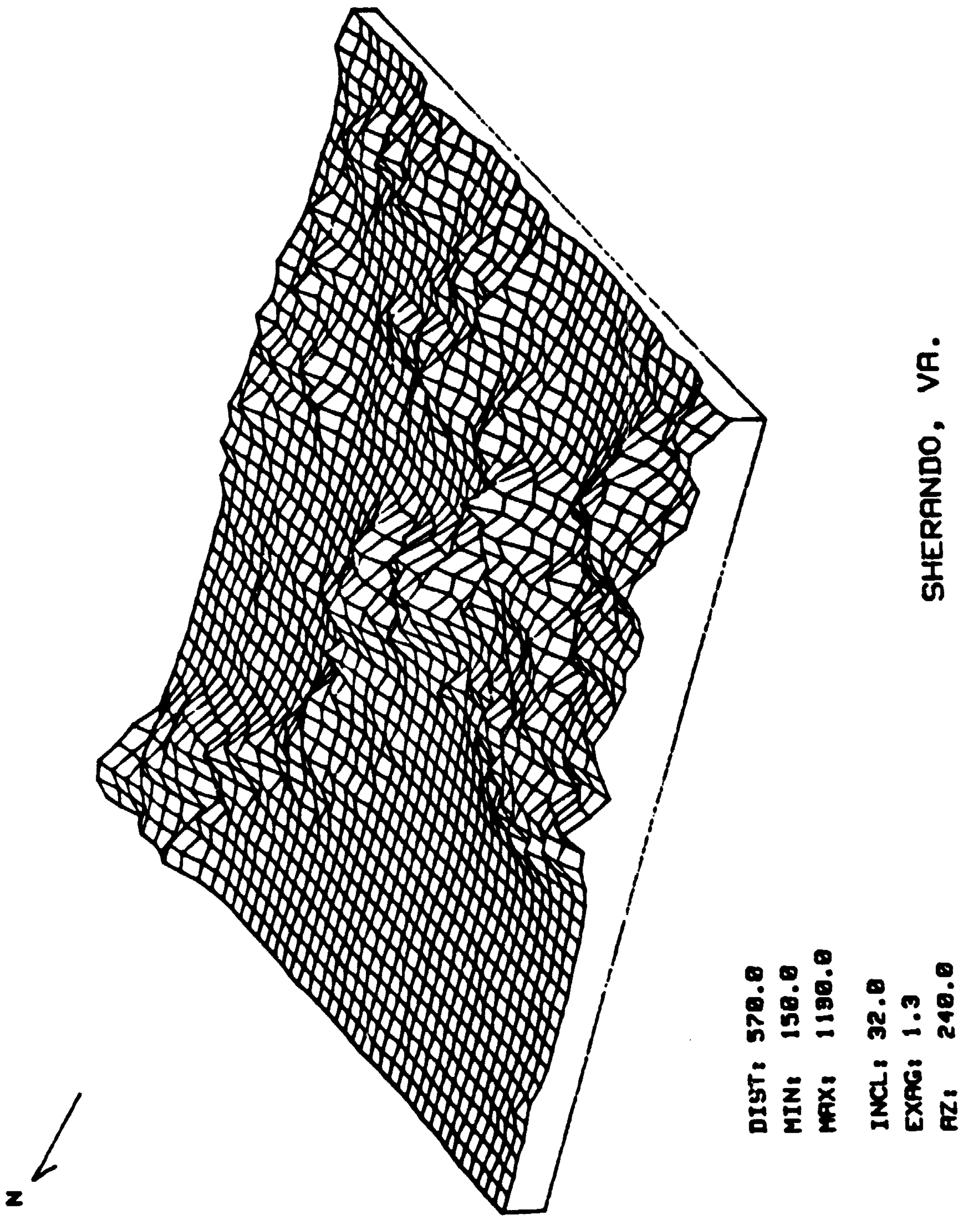

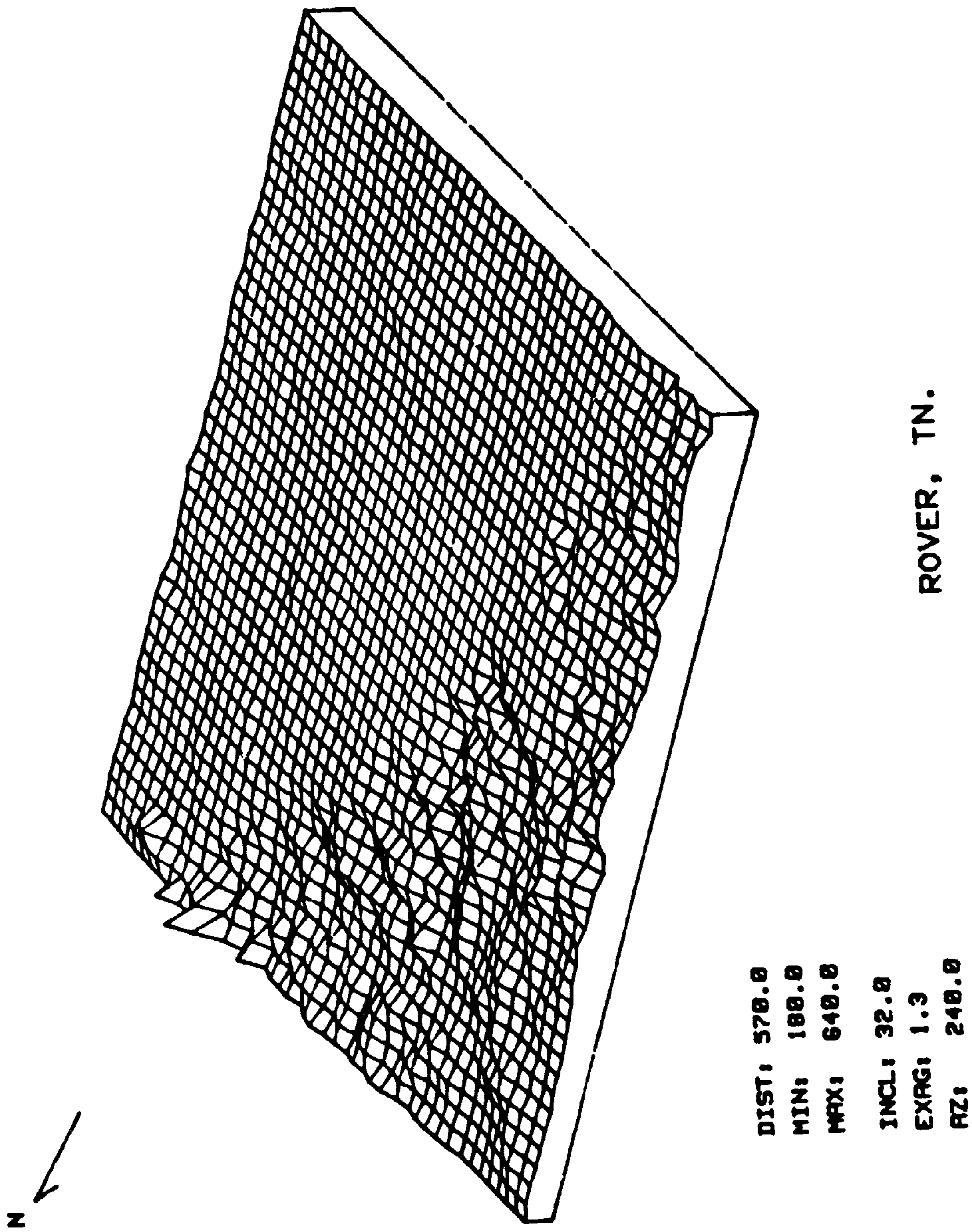
ROVER, TN.
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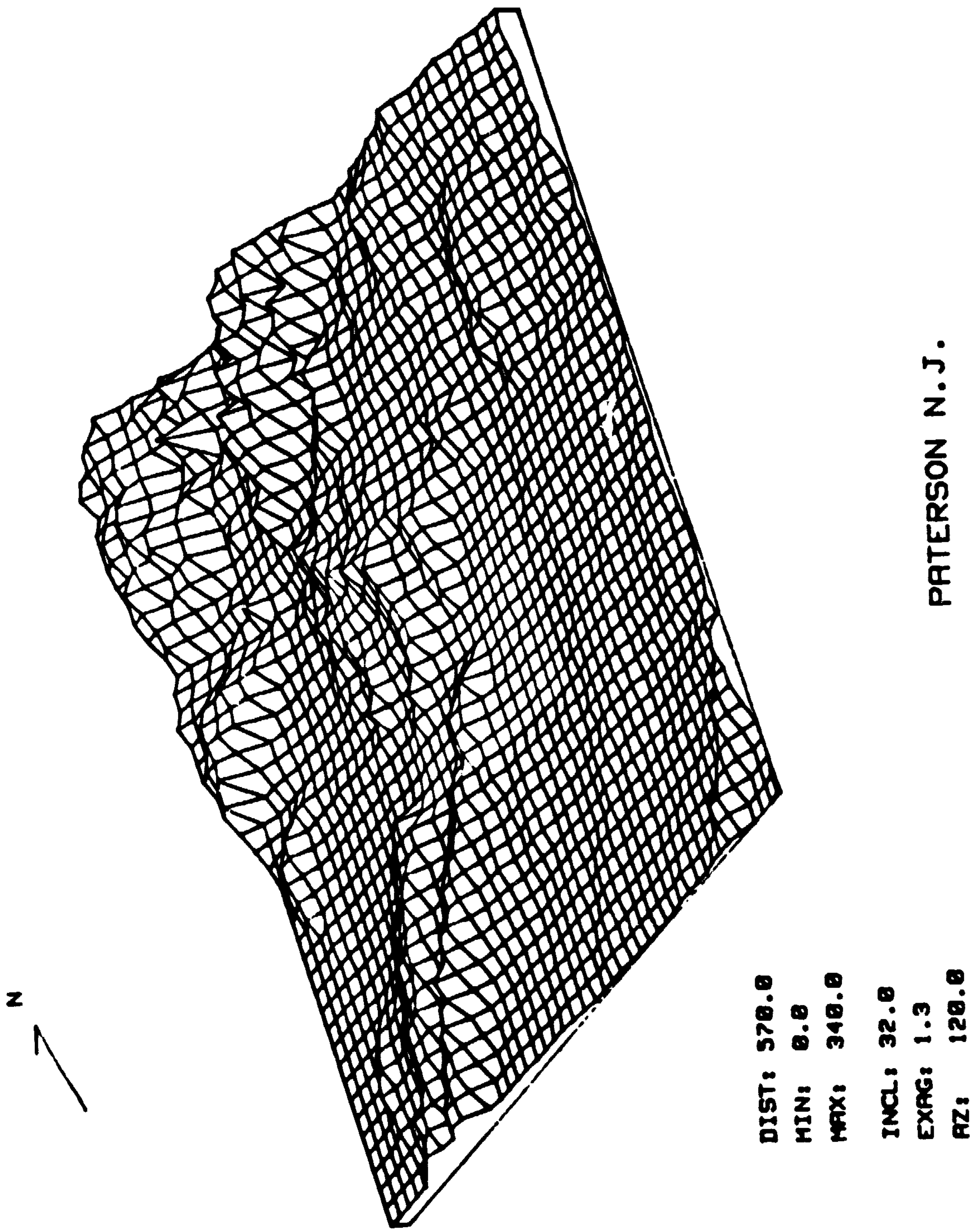
PATERSON N.J.
N
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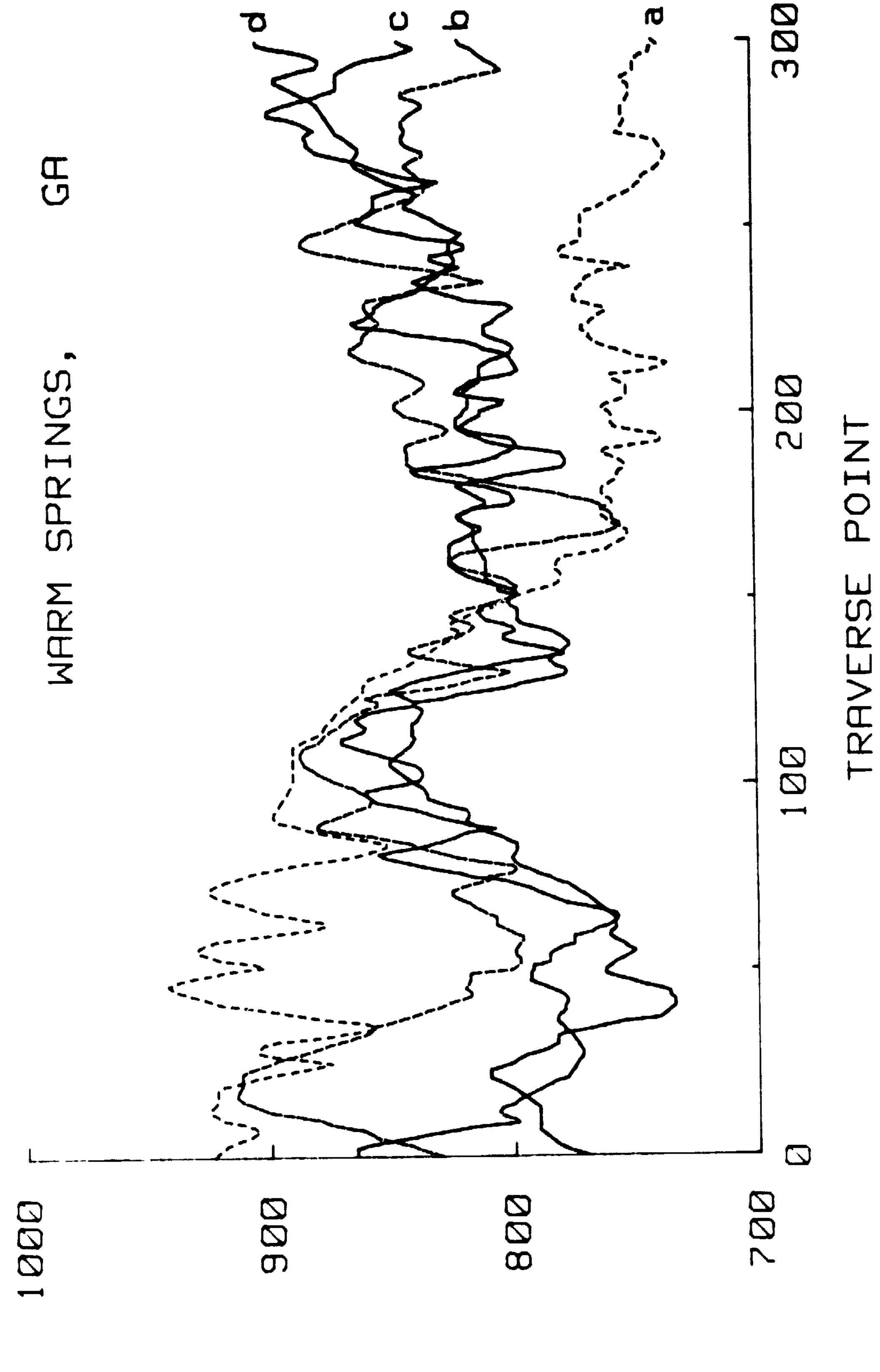

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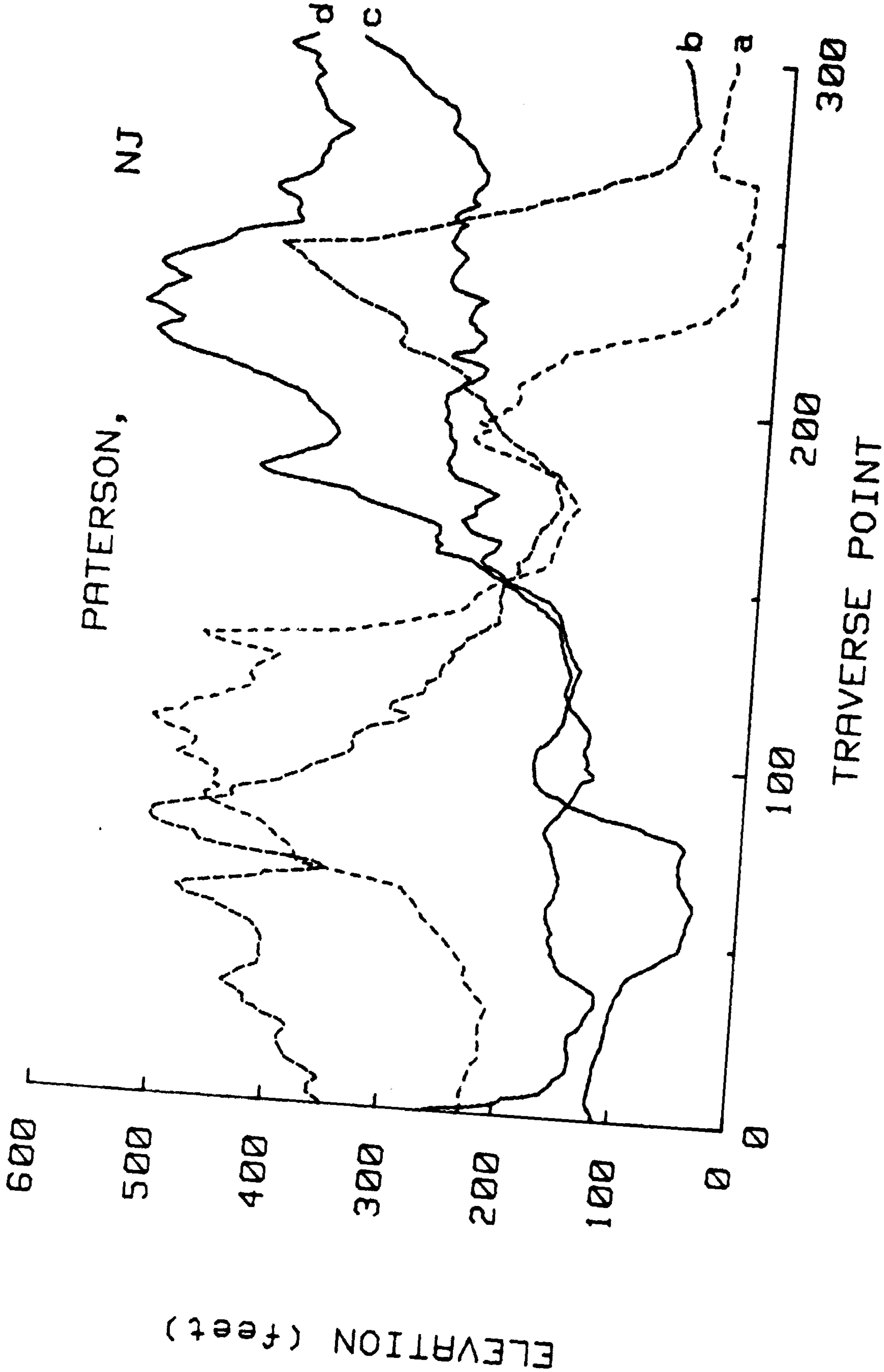

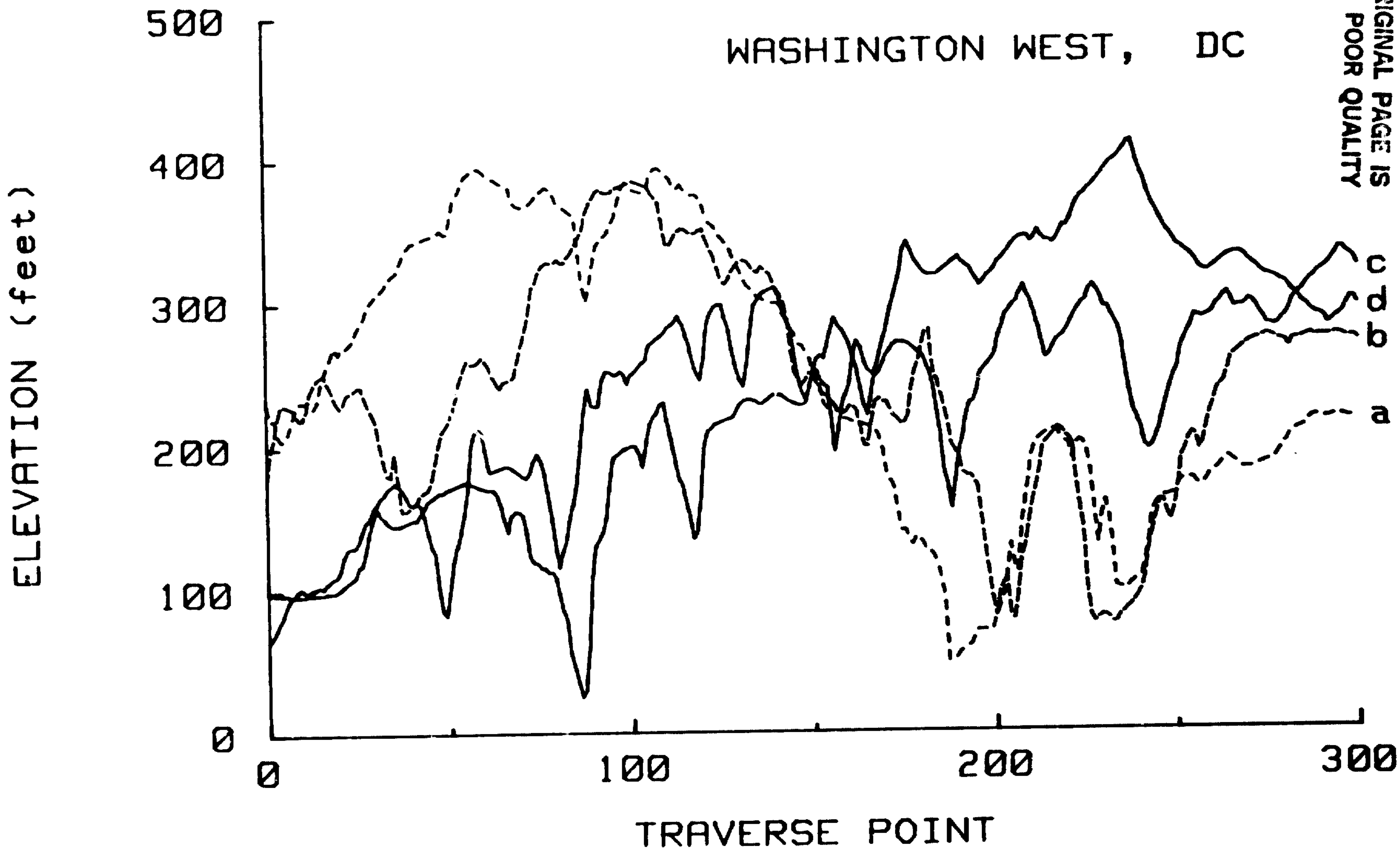

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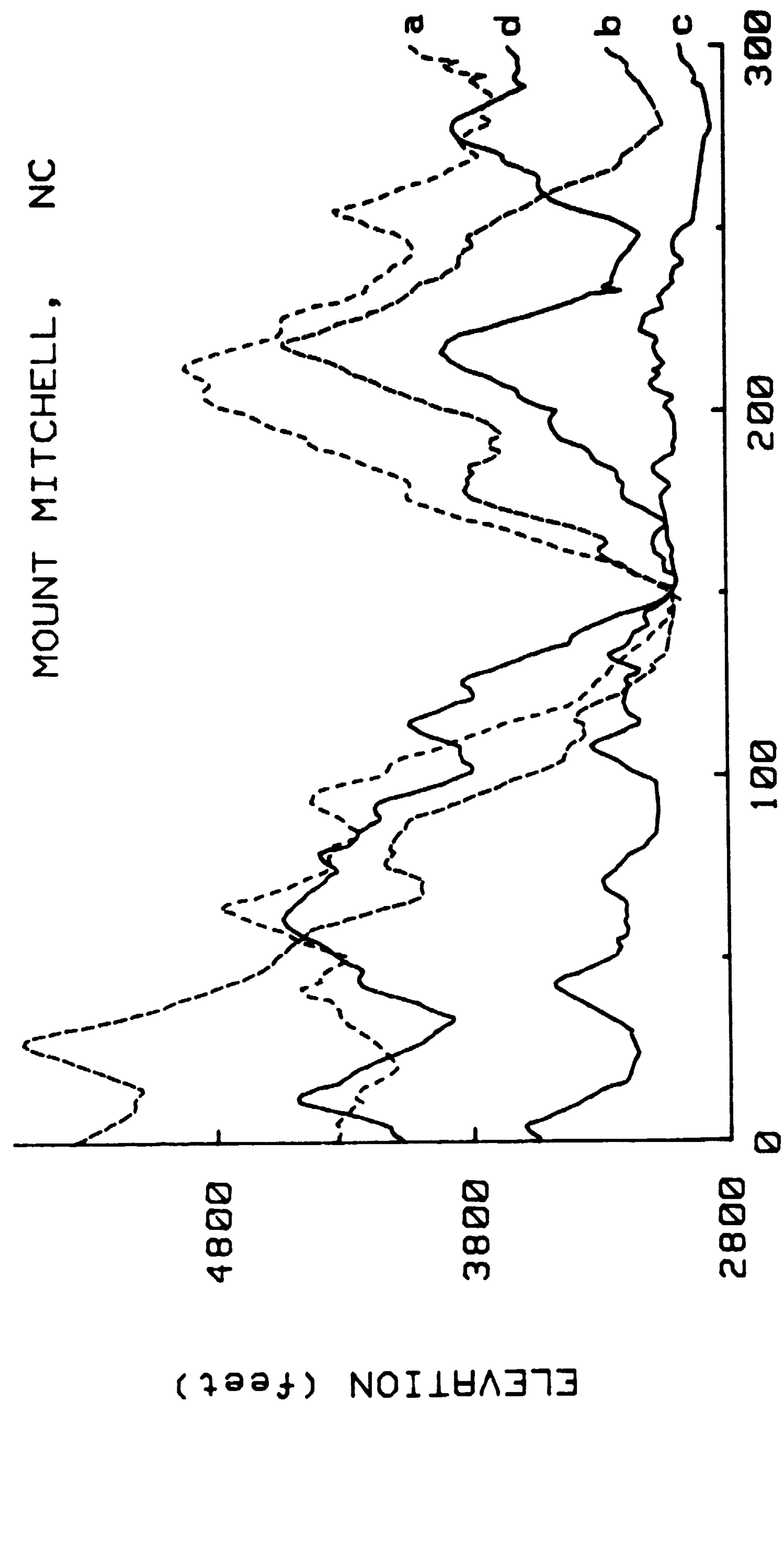
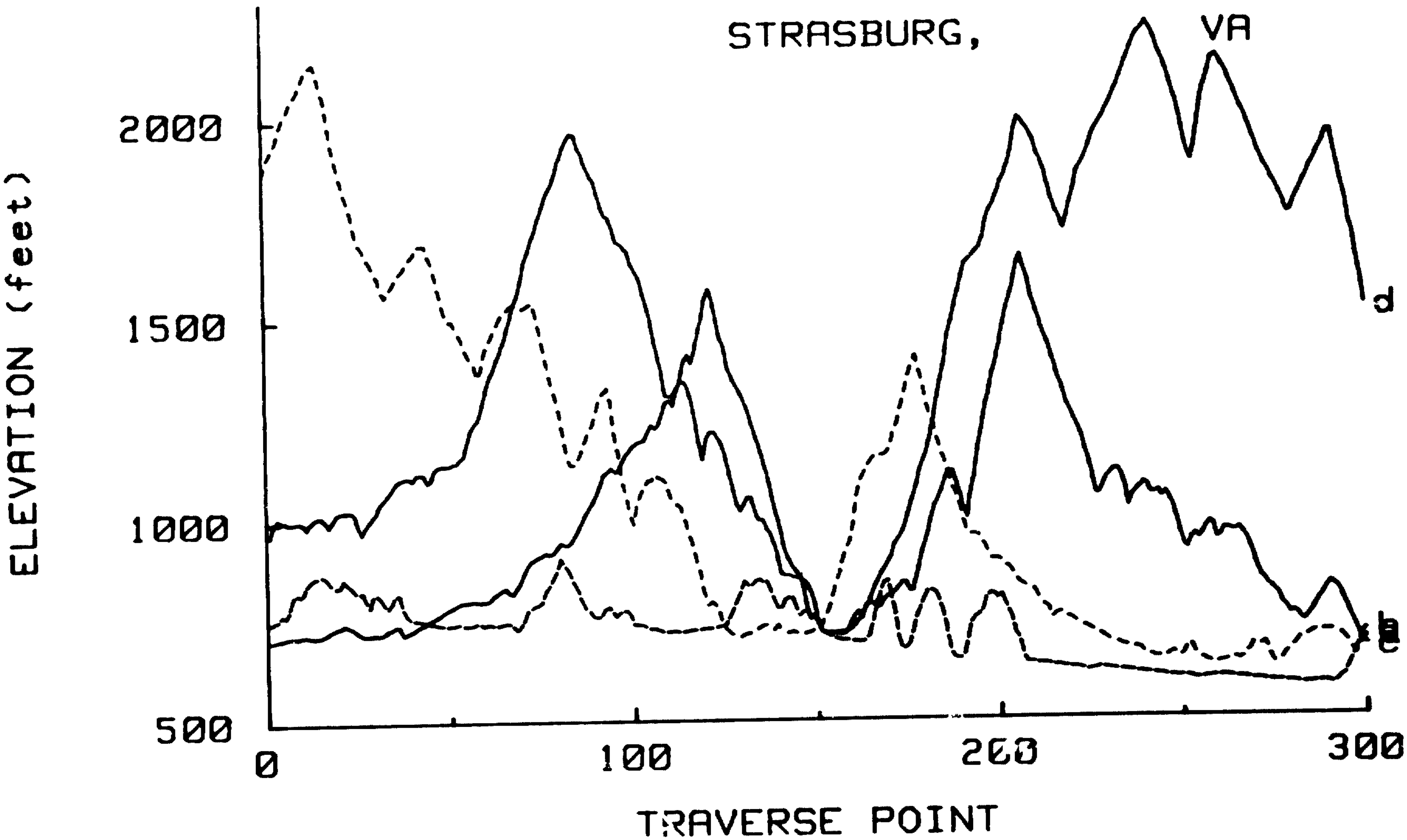
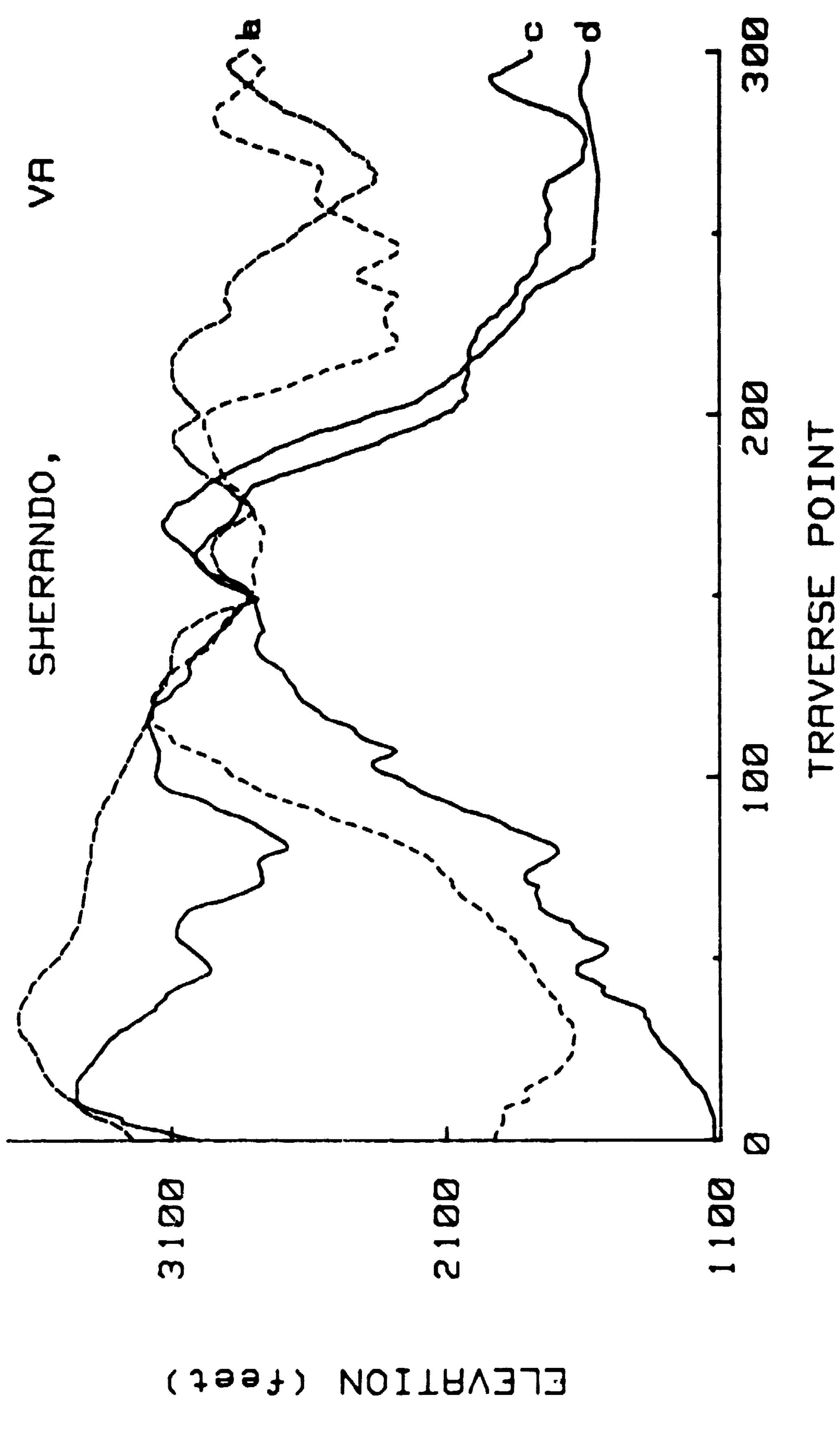

MOUNT MITCHELL, NC
a
d
b
c
ELEVATION (feet)
4800
3800
2800
0
100
200
300
TRAVERSE POINT


STRASBURG, VA
ELEVATION (feet)
2000
1500
1000
500
0
100
200
300
TRAVERSE POINT
d
a
b
c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ELEVATION (feet)
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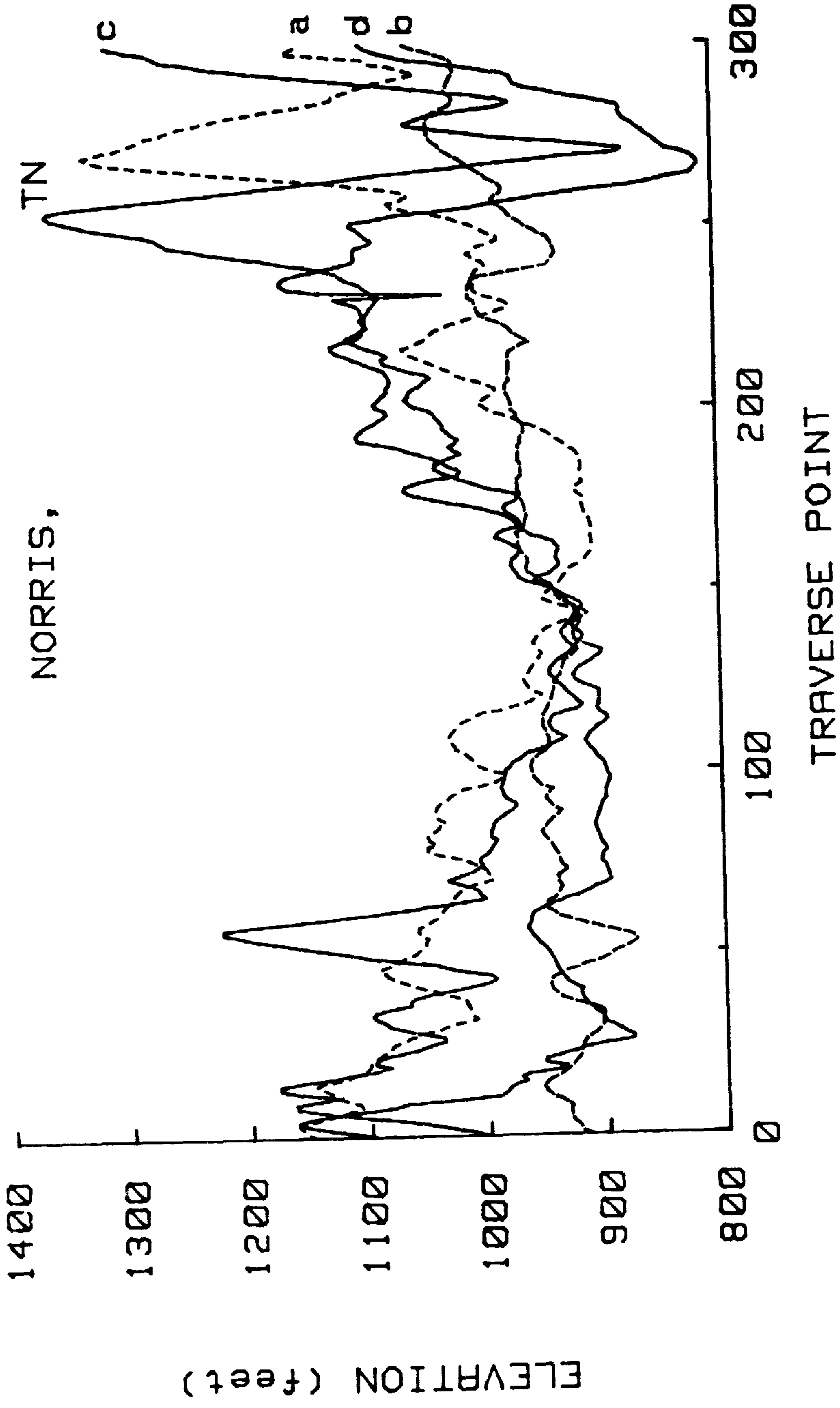
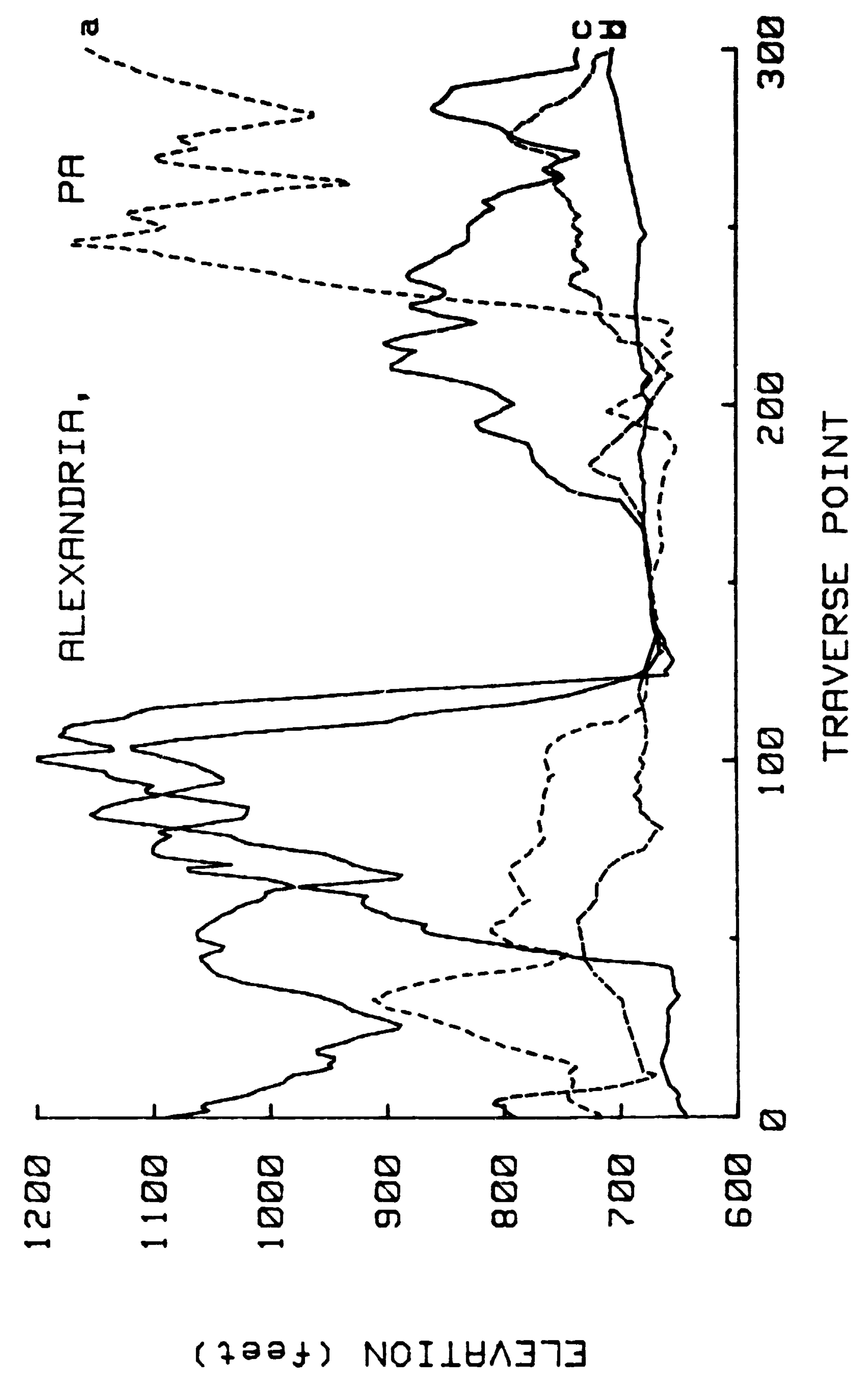
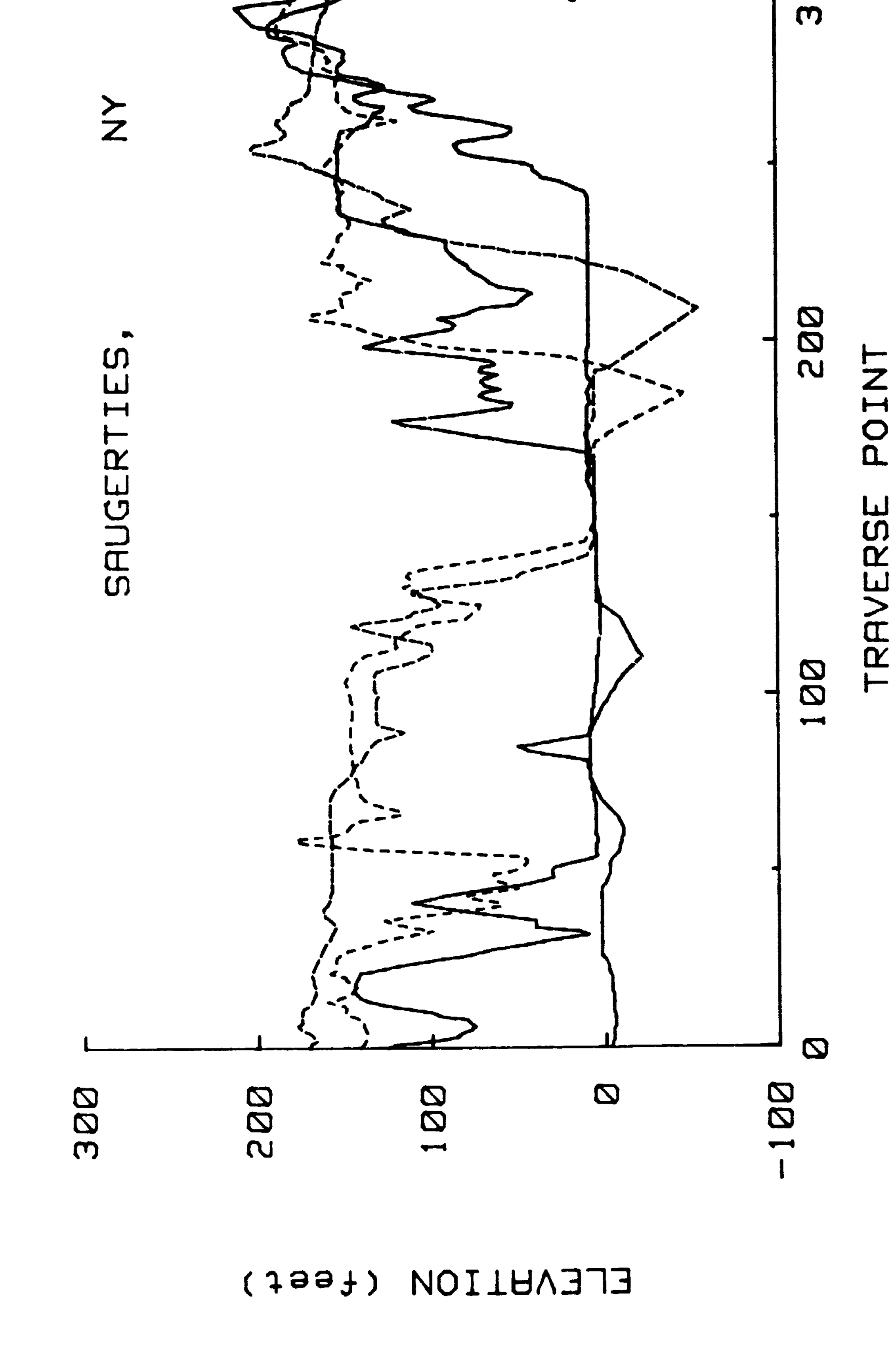
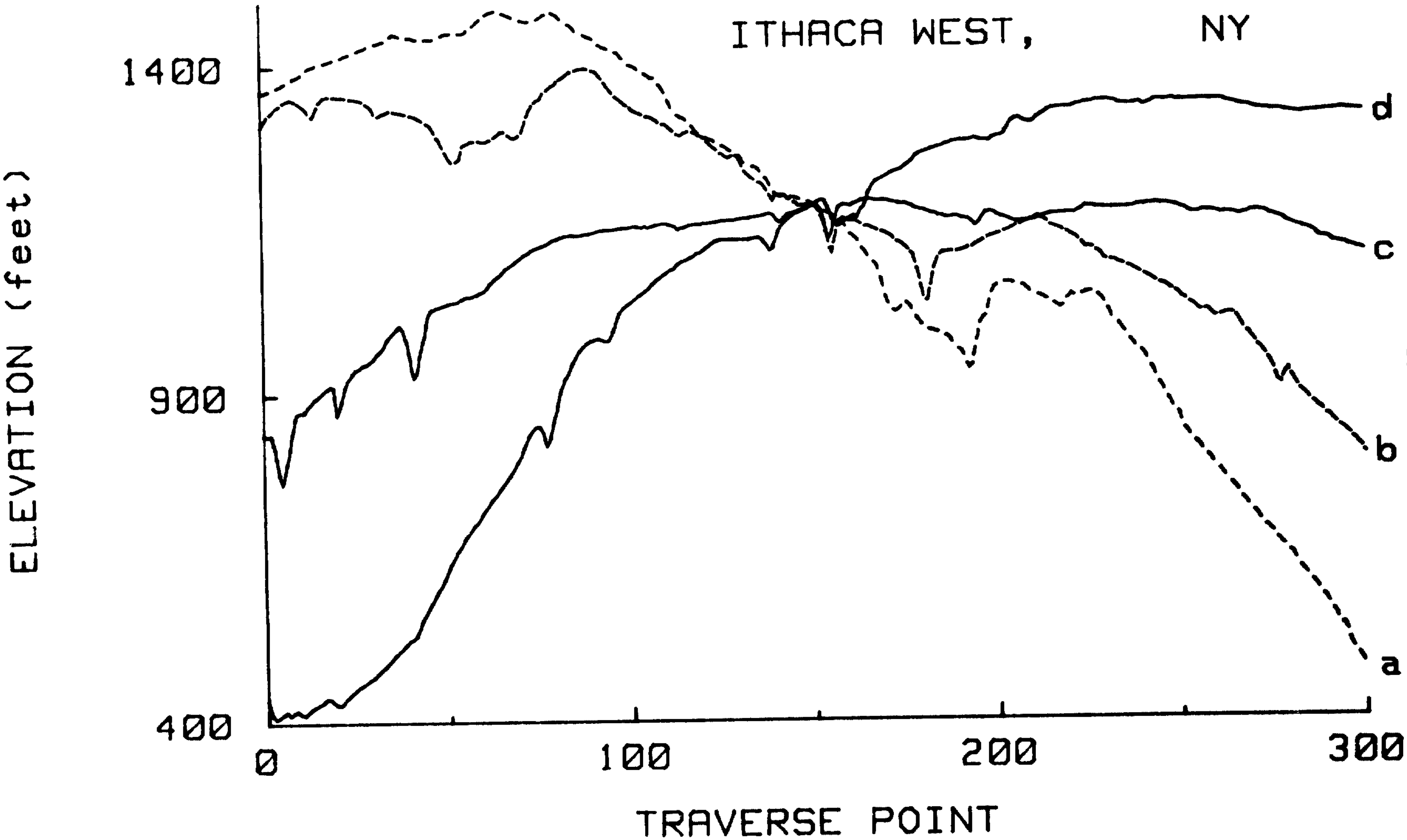
2100
1100
0
100
200
300
TRAVERSE POINT
b
c
d


NORRIS, TN
a
b
c
d
TRAVERSE POINT
0
100
200
300
ELEVATION (feet)
800
900
1000
1100
1200
1300
1400


ALEXANDRIA, PA
a
c
b
1200
1100
1000
900
800
700
600
0
100
200
300
TRAVERSE POINT
ELEVATION (feet)


SAUGERTIES, NY
ELEVATION (feet)
TRAVERSE POINT
300
200
100
0
-100
0
100
200
300
C


ITHACA WEST, NY
ELEVATION (feet)
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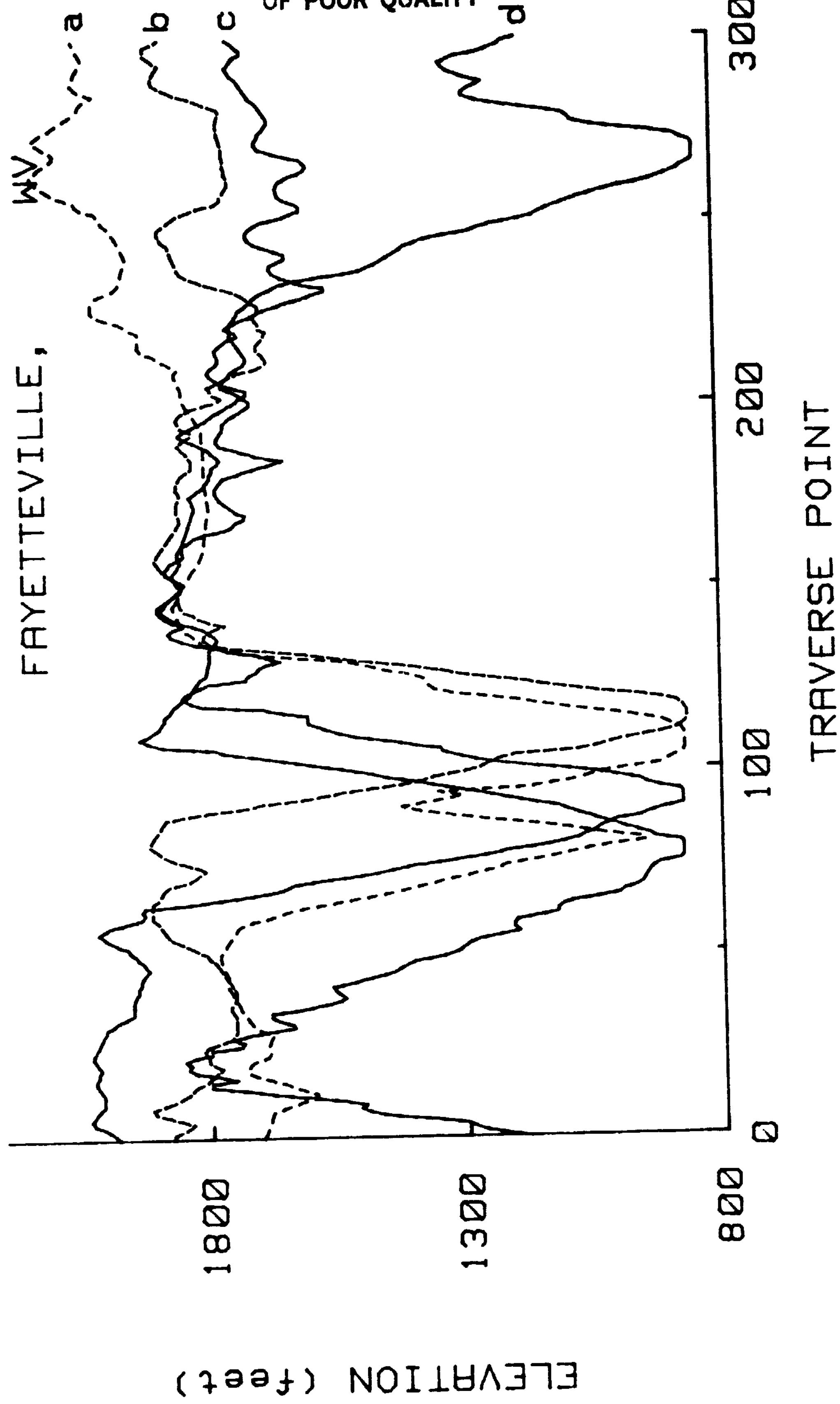
900
400
0
100
200
300
TRAVERSE POINT
a
b
c
d


FAYETTEVILLE, WV
a
b
c
d
TRAVERSE POINT
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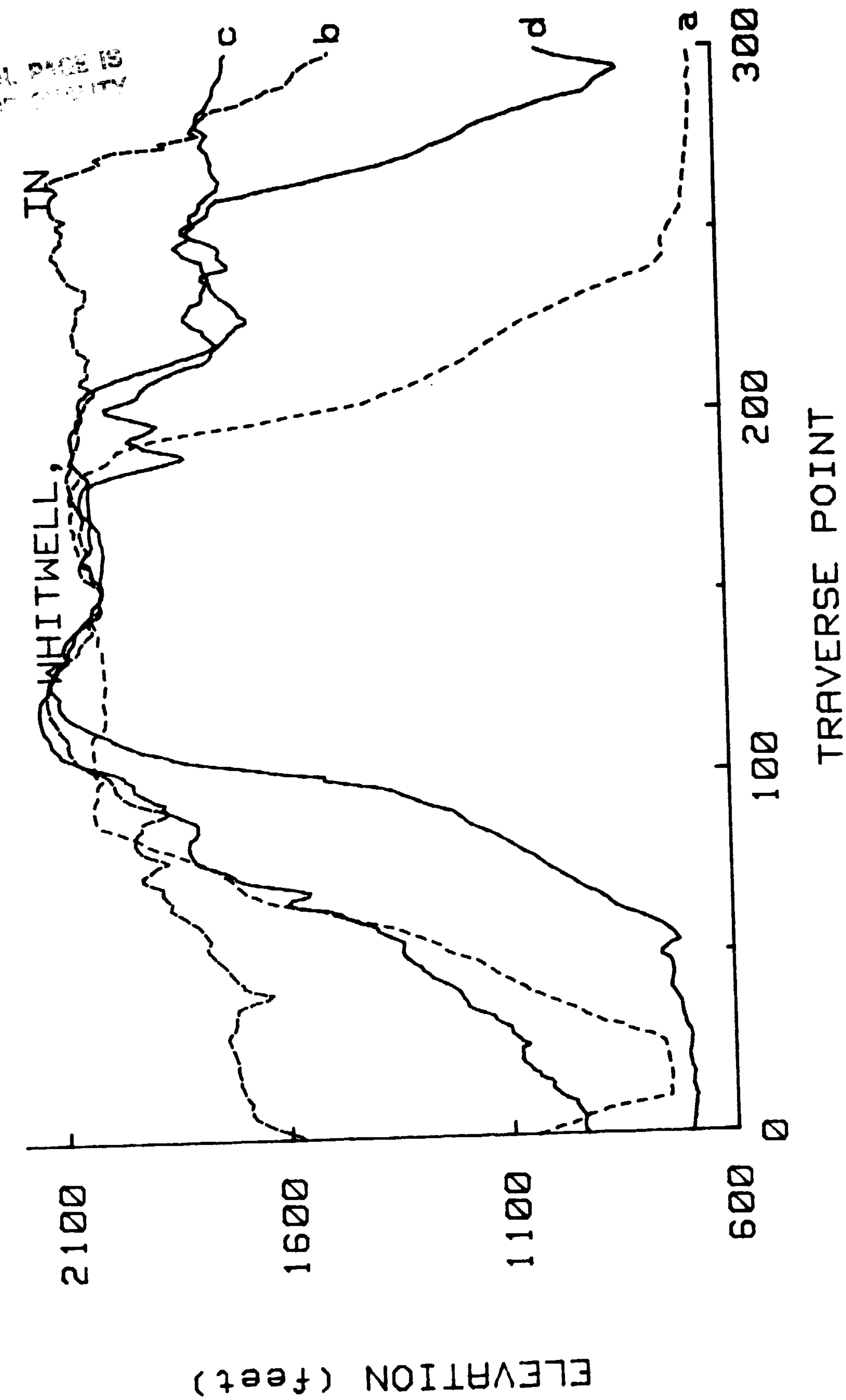
100
200
300
ELEVATION (feet)
800
1300
1800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b
c
d
IN
WHITWELL
TRAVERSE POINT
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100
200
300
ELEVATION (feet)
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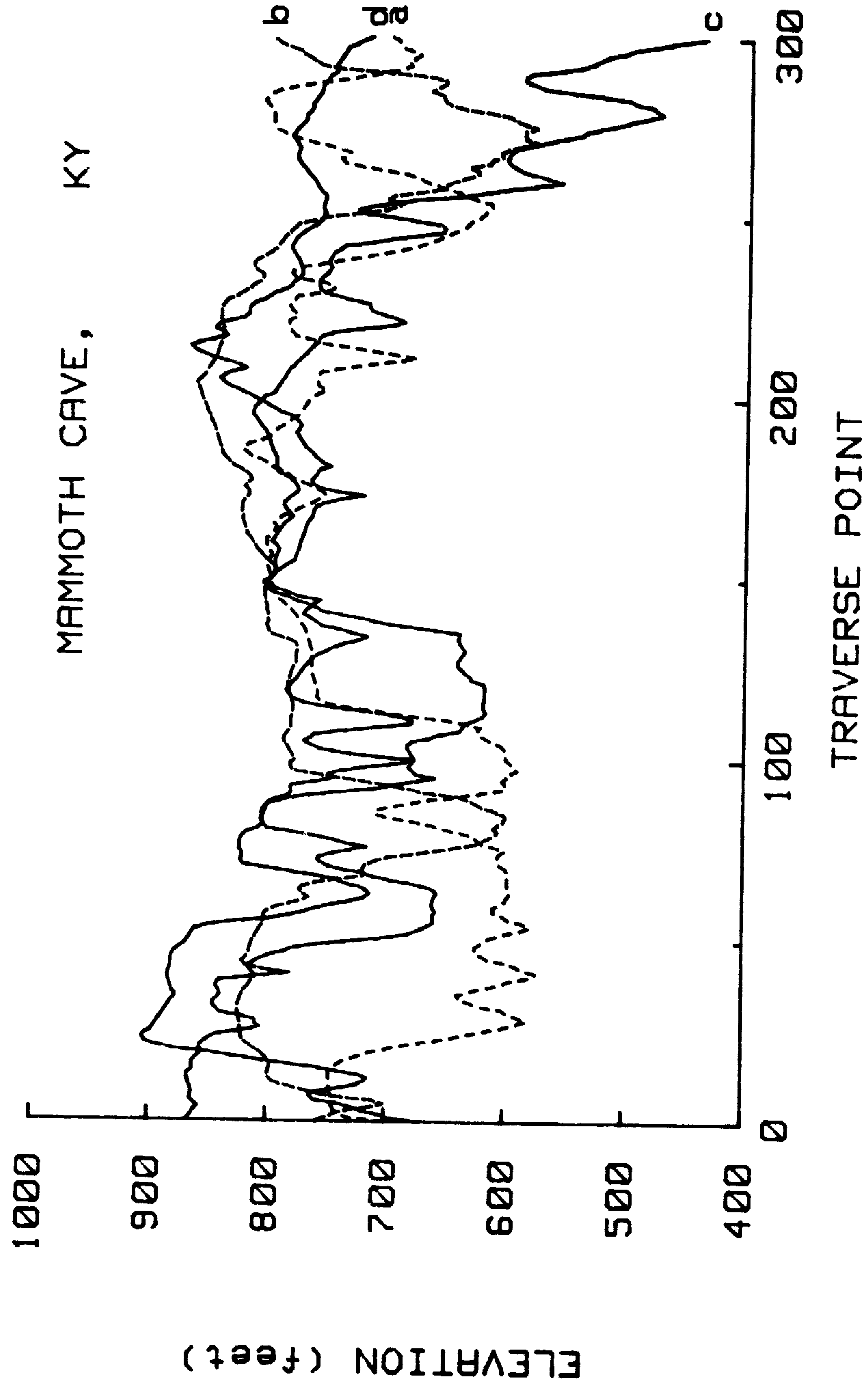
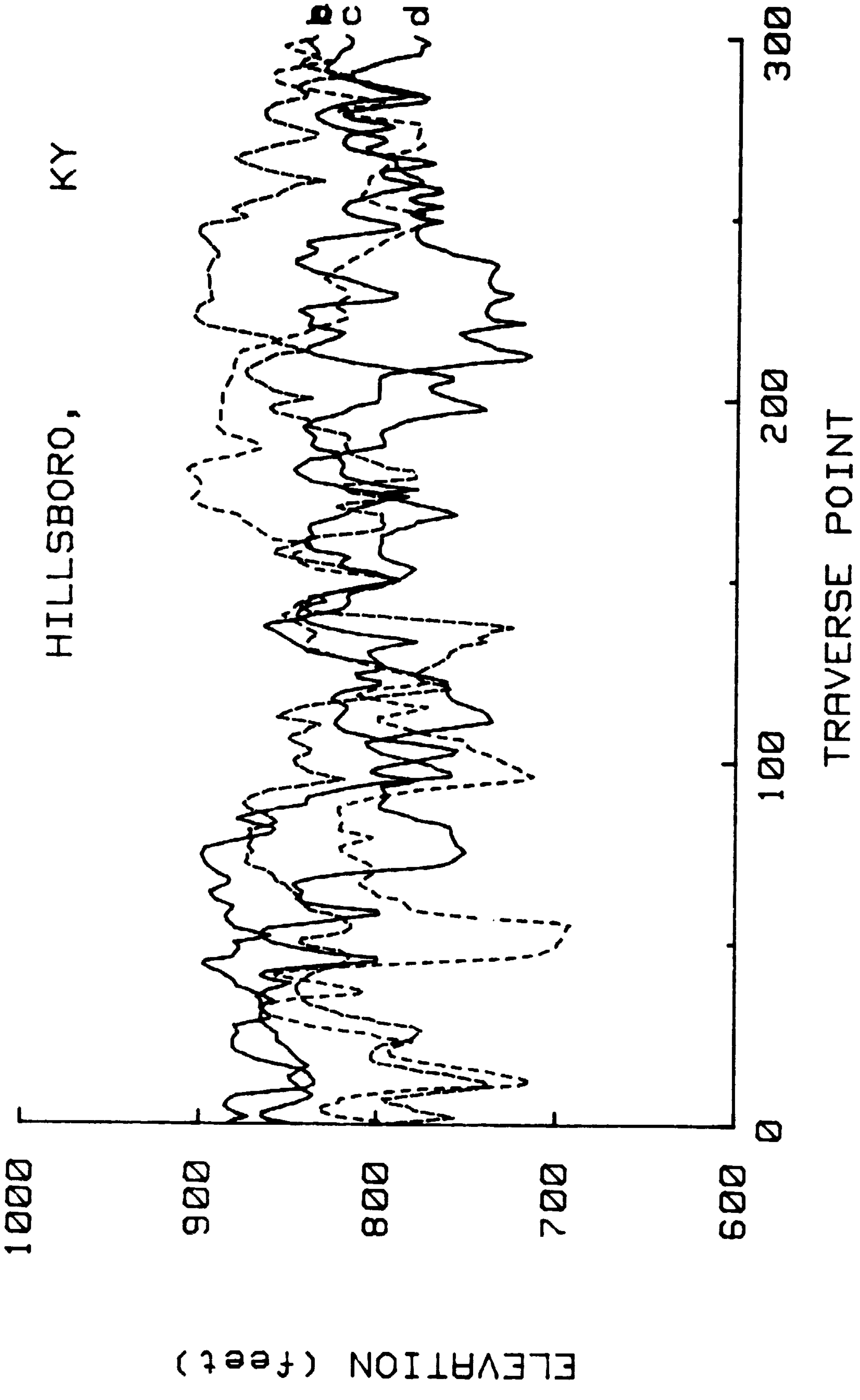
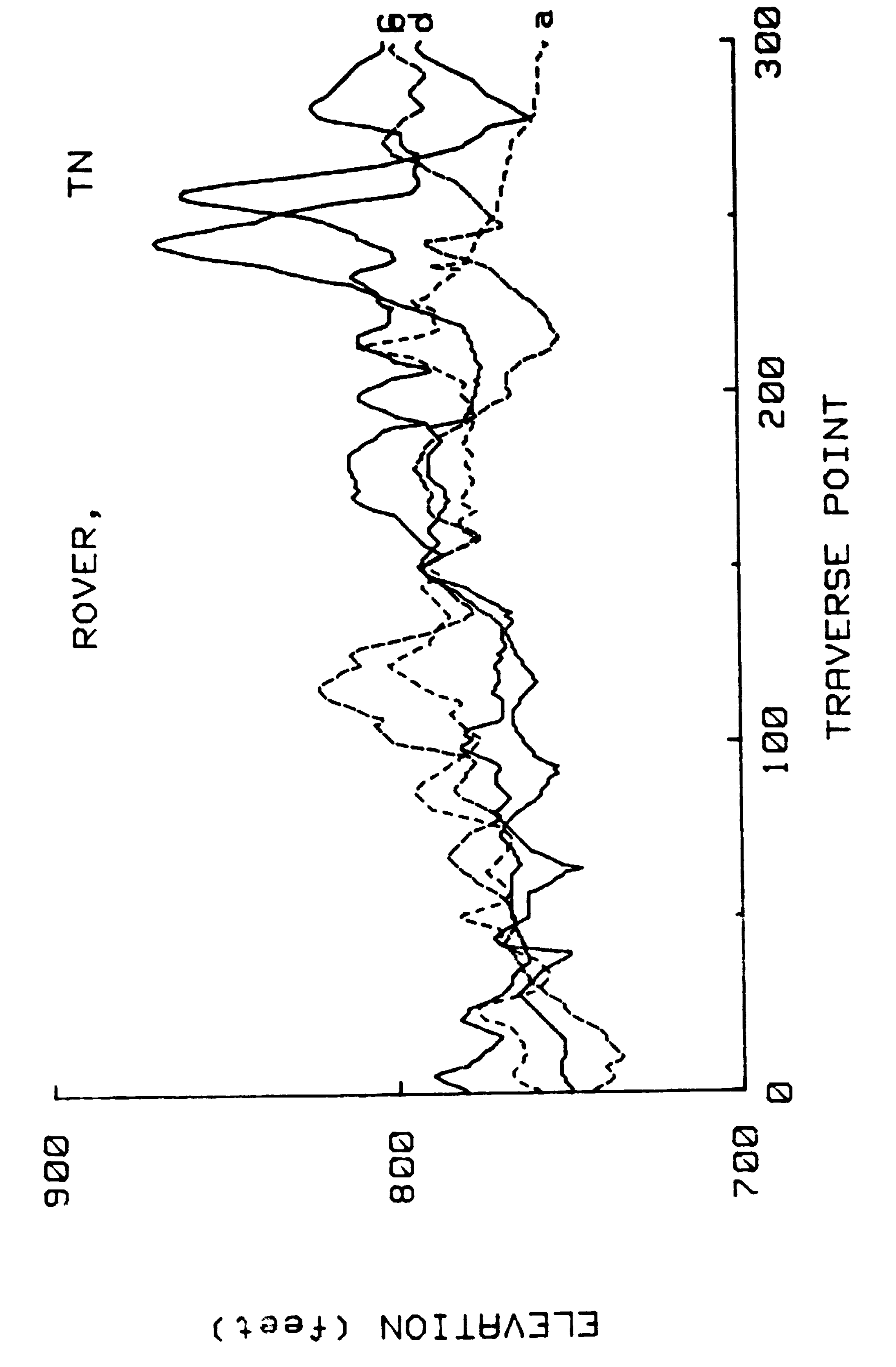
1100
1600
2100


MAMMOTH CAVE, KY
ELEVATION (feet)
TRAVERSE POINT
1000
900
800
700
600
500
400
0
100
200
300
a
b
c
d


HILLSBORO, KY
ELEVATION (feet)
1000
900
800
700
600
TRAVERSE POINT
0
100
200
300
a
b
c
d


ROVER, TN
ELEVATION (feet)
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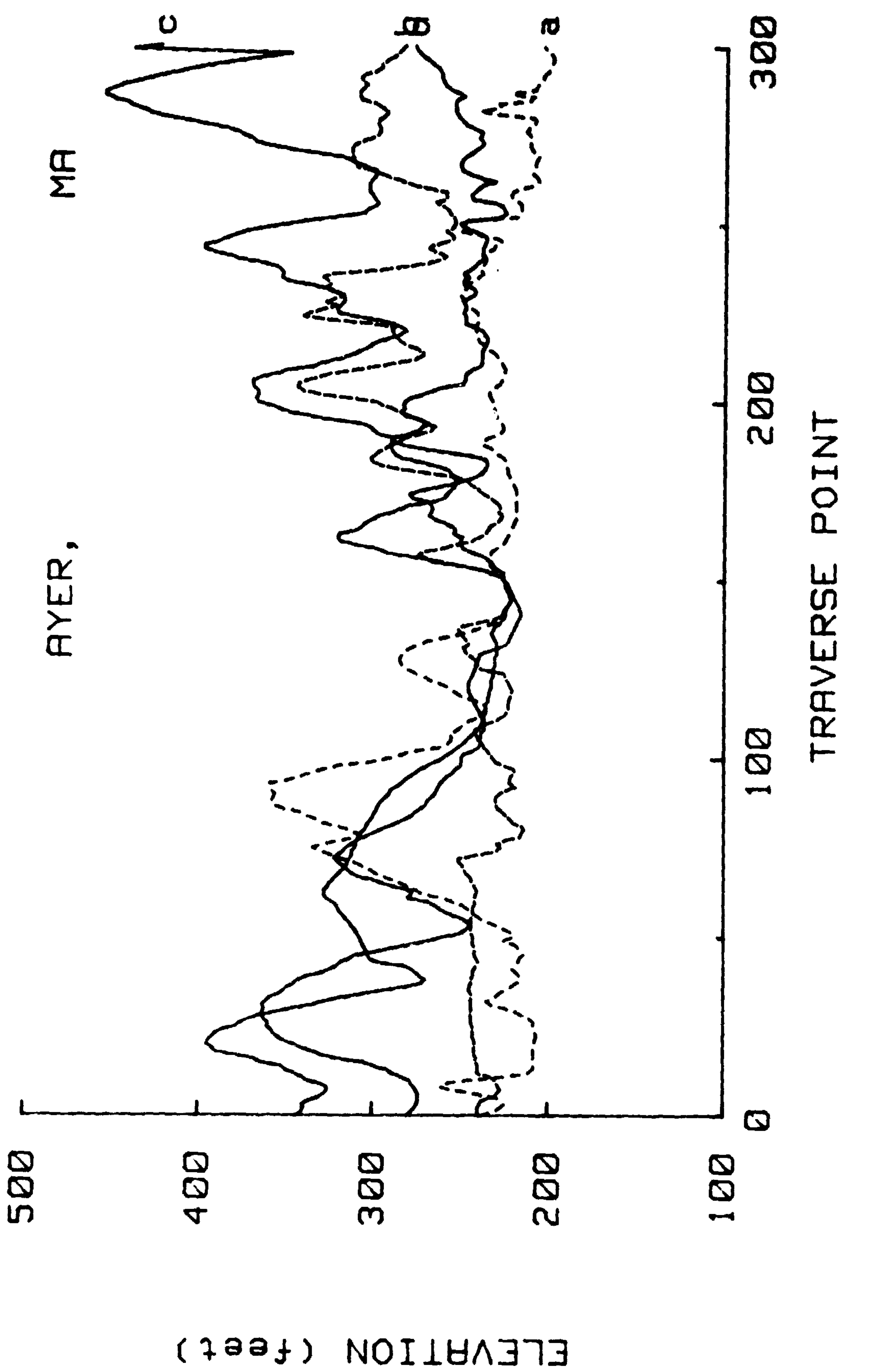
800
700
TRAVERSE POINT
0
100
200
300


AYER, MA
ELEVATION (feet)
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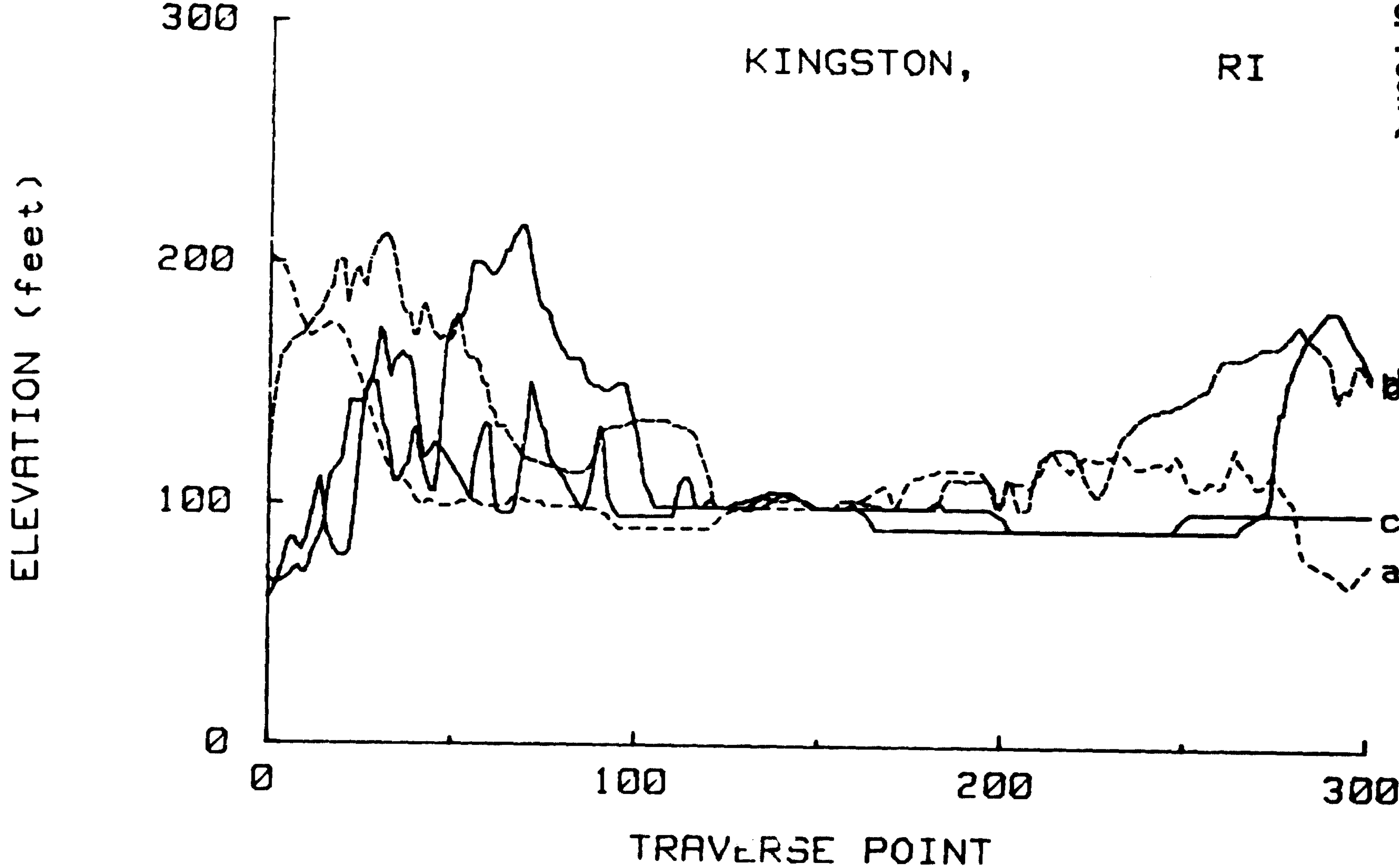
400
300
200
100
TRAVERSE POINT
0
100
200
300
a
b
c


KINGSTON, RI
ELEVATION (feet)
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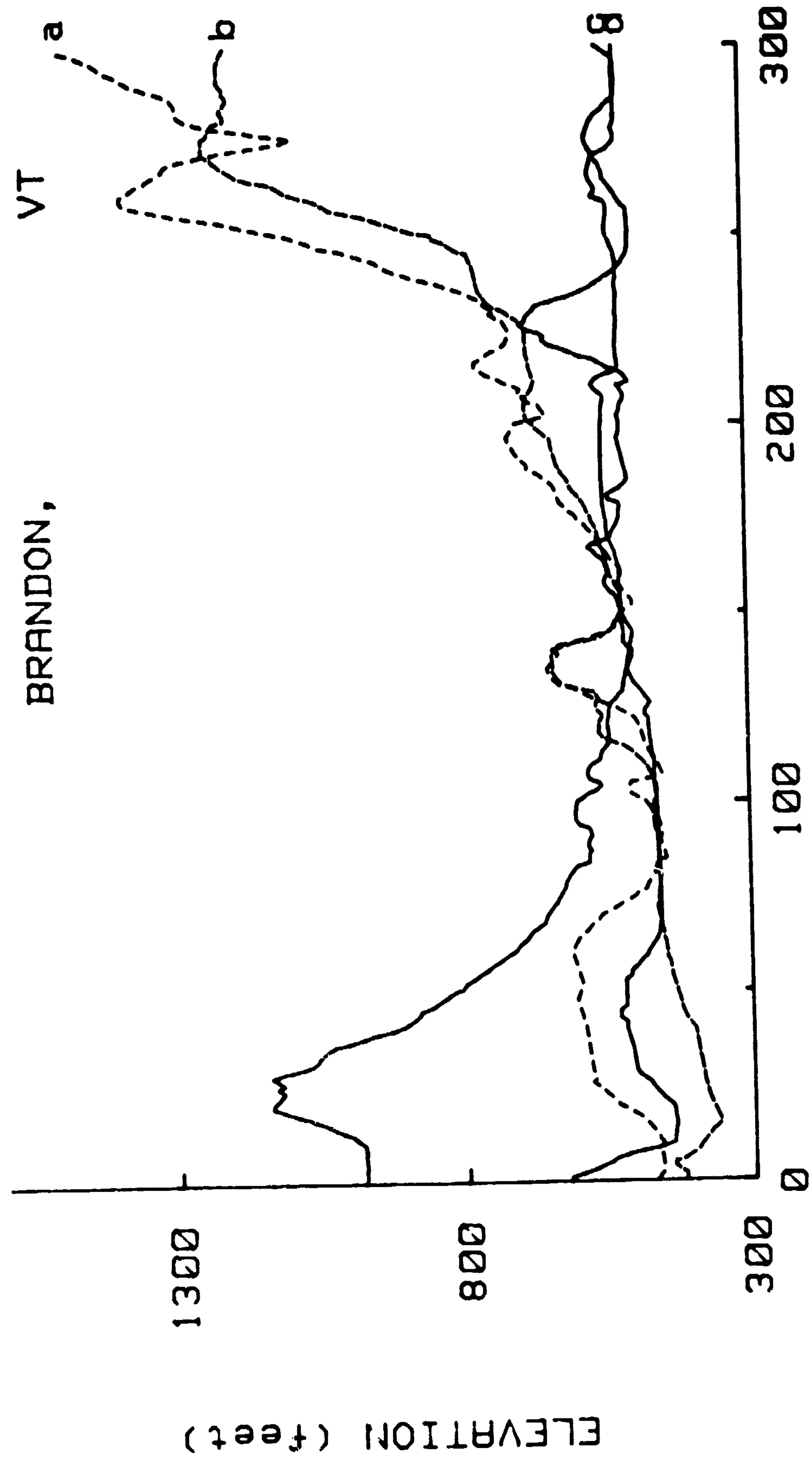
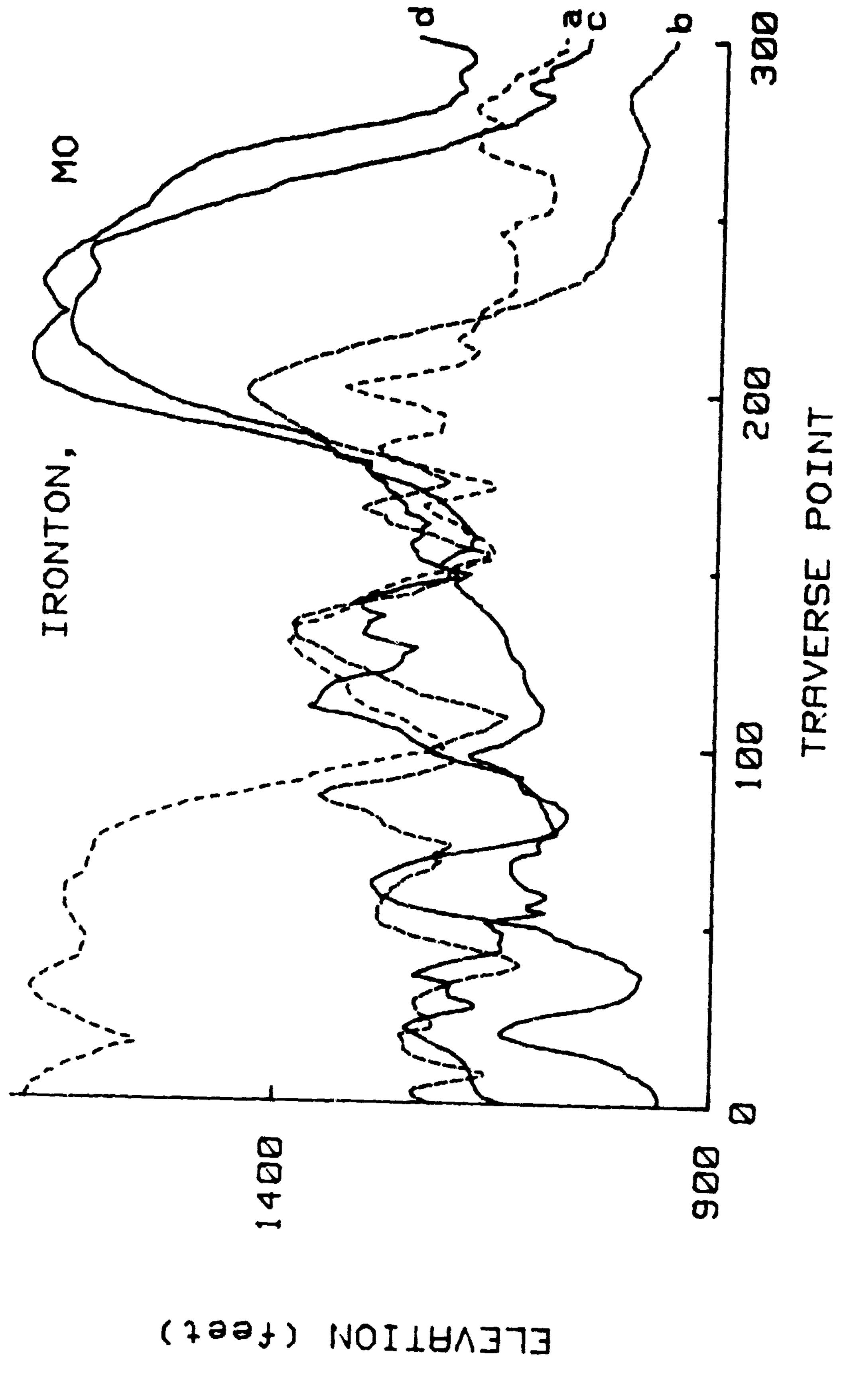
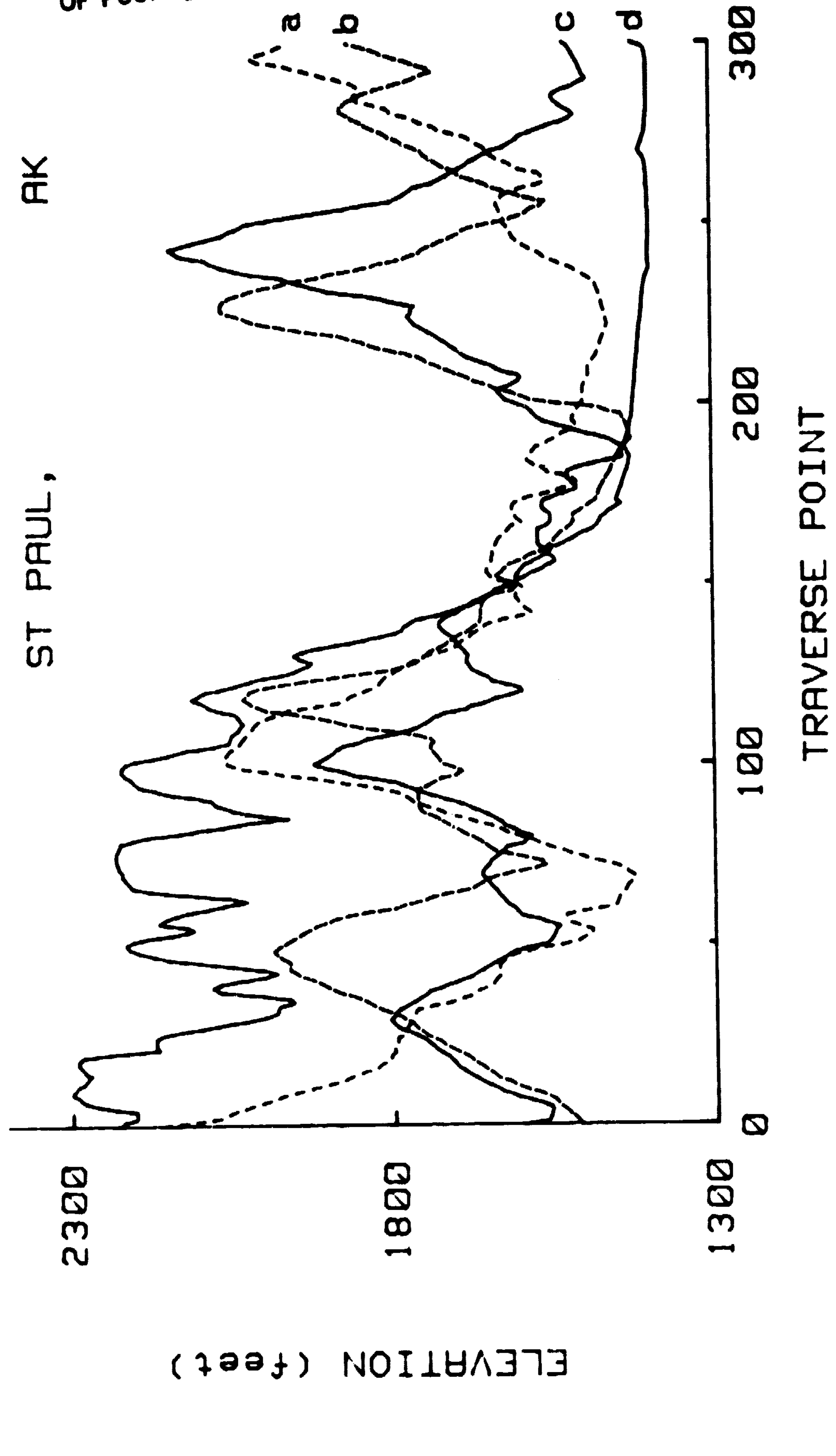
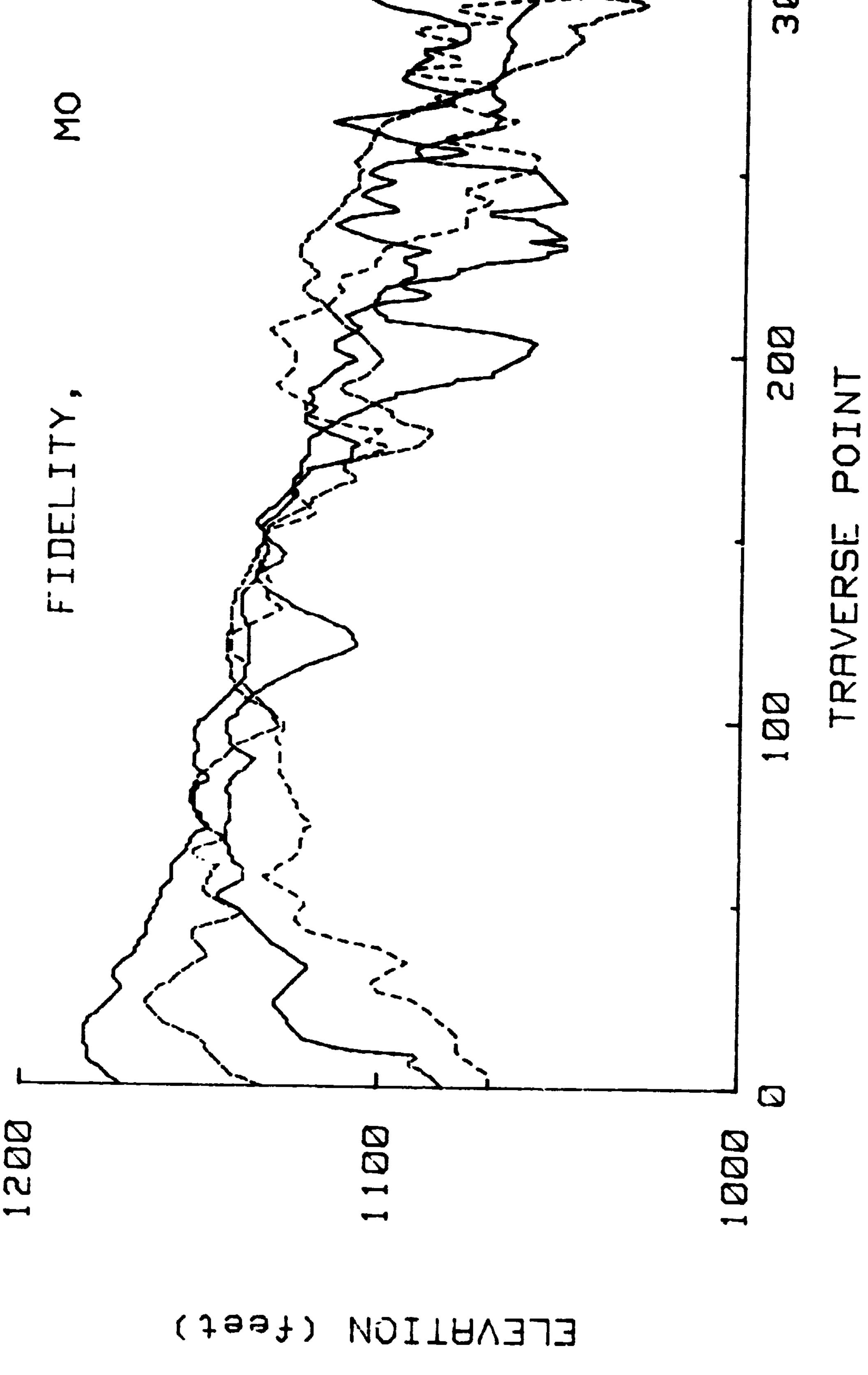
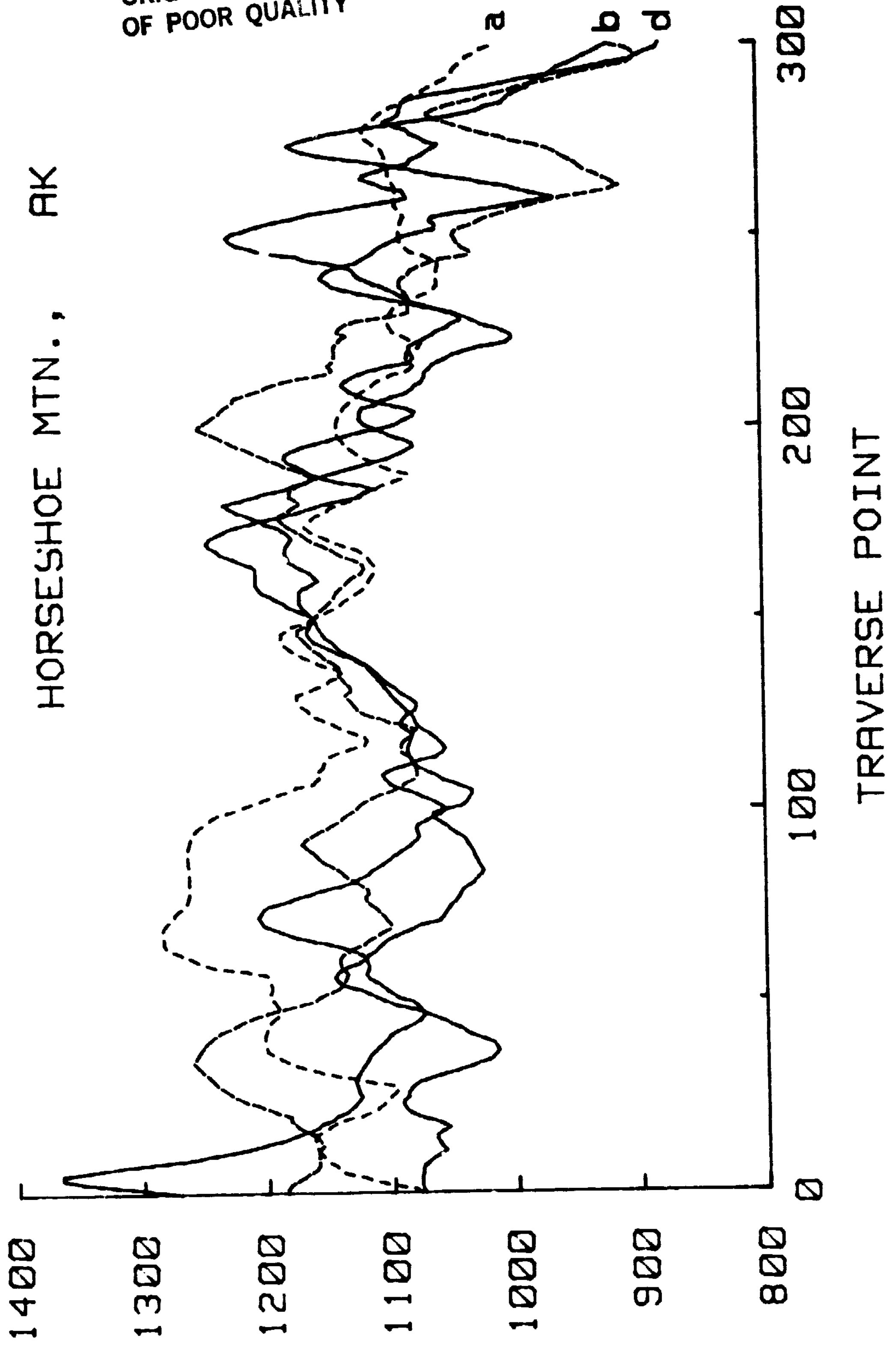
0
100
200
300
TRAVERSE POINT
a
b
c
d

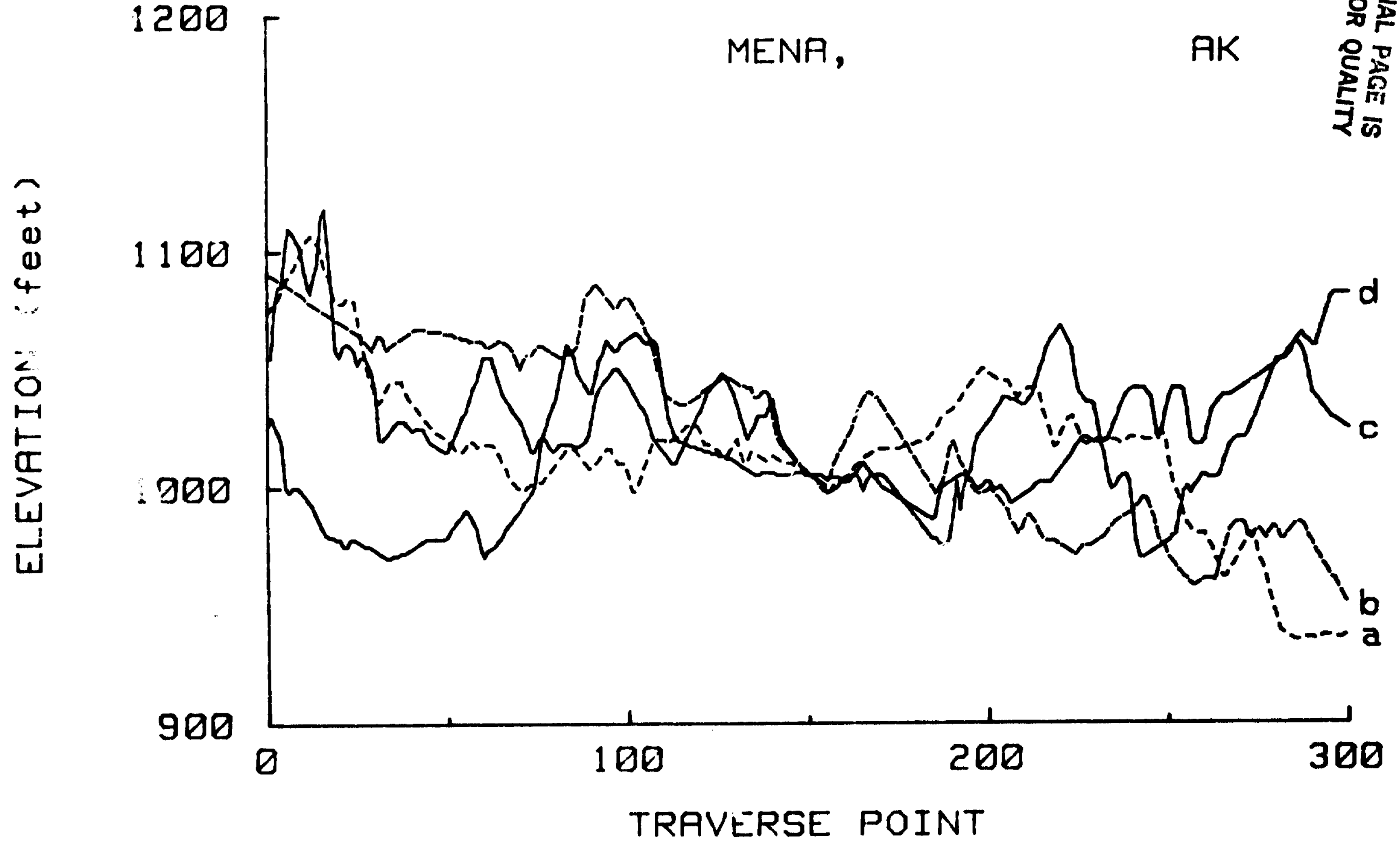

BRANDON, VT
a
b
g
TRAVERSE POINT
0
100
200
300
ELEVATION (feet)
300
800
1300


IRONTON, MO
d
a
c
b
ELEVATION (feet)
1400
900
TRAVERSE POINT
0
100
200
300


ST PAUL, AK
a
b
c
d
2300
1800
1300
ELEVATION (feet)
0
100
200
300
TRAVERSE POINT


FIDELITY, MO
TRAVERSE POINT
ELEVATION (feet)
0
100
200
300
1000
1100
1200
a
b
c
d


HORSESHOE MTN., AK
a
b
d
ELEVATION (feet)
1400
1300
1200
1100
1000
900
800
TRAVERSE POINT
0
100
200
300


MENA, AK
ELEVATION (feet)
1200
1100
1000
900
0
100
200
300
TRAVERSE POINT
a
b
c
d

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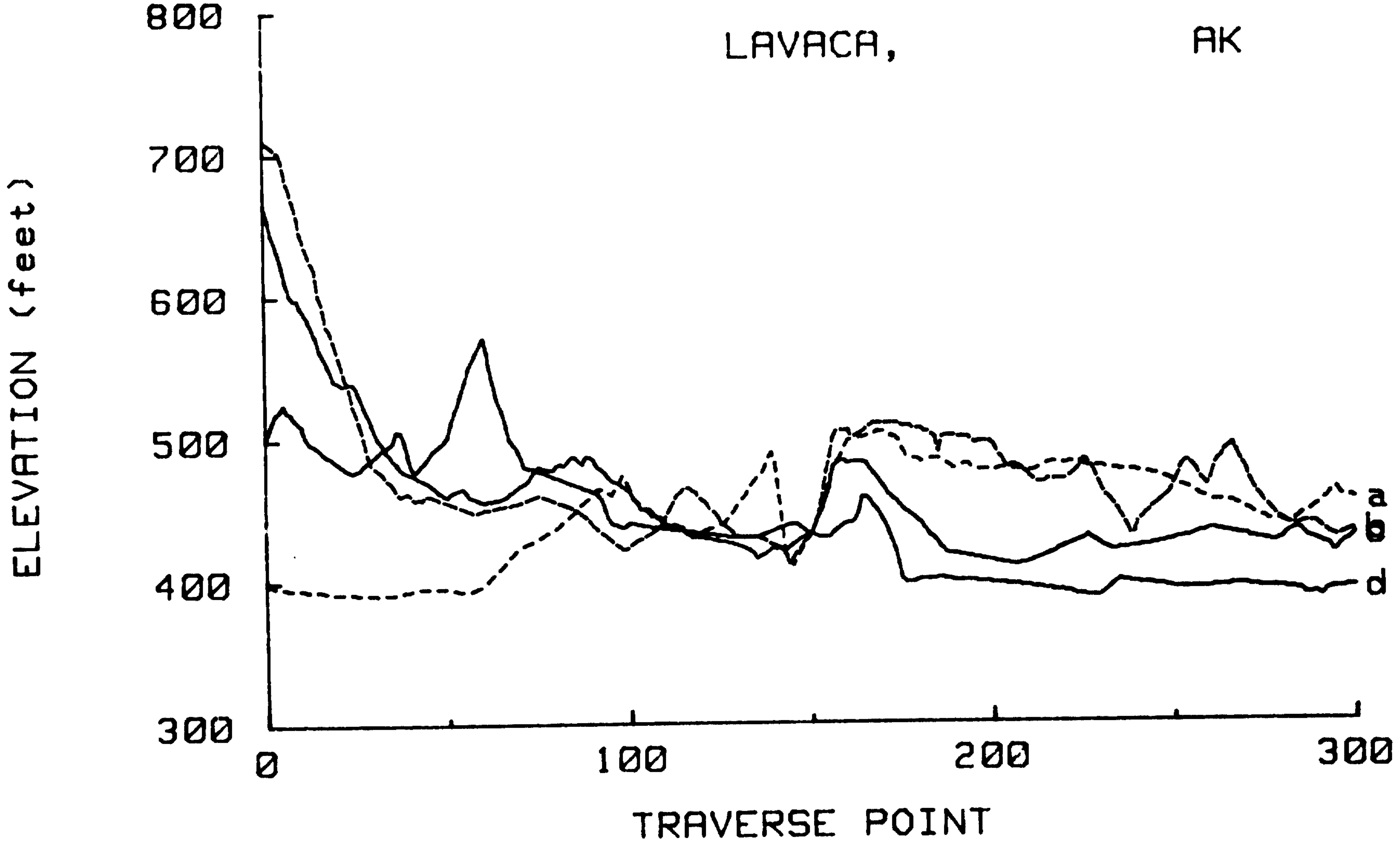
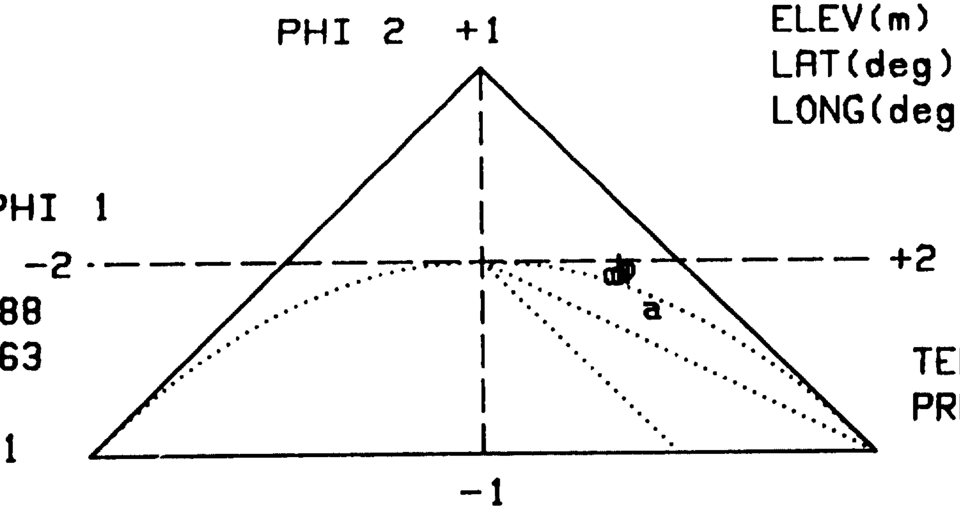
OF POOR QUALITY



WARM SPRINGS, GA

	PHI 1	PHI 2	A	B
MEAN	.75	-.10	.10	.65
S.D.	.08	.10	.10	.05

STATION	WOODBURY
DIST(km)	10.98
YEARS	59
ELEV(m)	243.84
LAT(deg)	32.98
LONG(deg)	84.58



LAT.	32.88
LONG.	84.63
C.I.	20
YEAR	1971

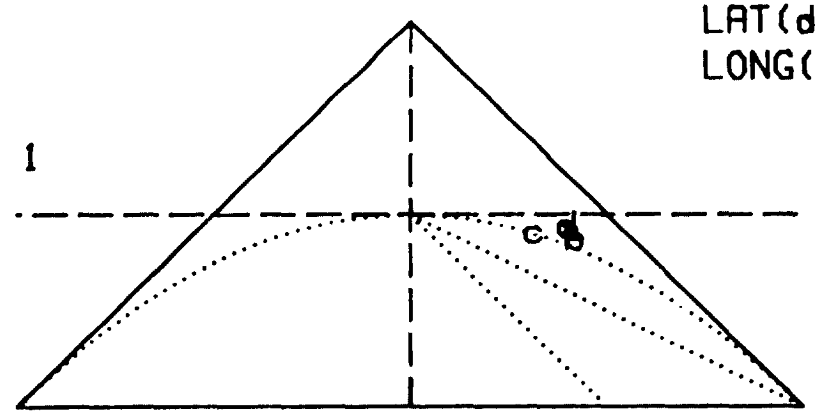
	MEAN	S.D.
TEMP.	X	0.00
PREC.	125.07	2.64

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.14	44	-.54	-.69	.20	.51	.86	-.24	.24	.62
b.	.14	42	-.50	-.65	.13	.52	.74	-.03	.03	.71
c.	.09	44	-.54	-.70	.24	.40	.67	-.06	.06	.61
d.	.78	46	-.53	-.69	.19	.45	.71	-.06	.06	.65

PATERSON, NJ

	PHI 1	PHI 2	A	B
MEAN	.77	-.08	.08	.69
S.D.	.09	.03	.03	.09

STATION	PATERSON
DIST(km)	5.22
YEARS	86
ELEV(m)	30.48
LAT(deg)	40.9
LONG(deg)	74.15



LAT.	40.88
LONG.	74.13
C.I.	10
YEAR	808

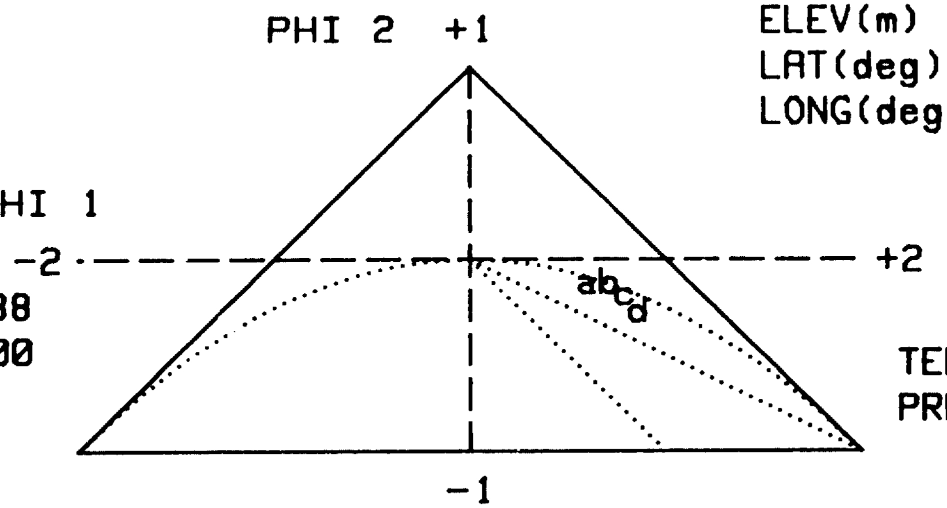
	MEAN	S.D.
TEMP.	11.44	9.26
PREC.	124.76	1.08

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.55	67	-.53	-.70	.73	.58	.81	-.07	.07	.74
b.	.86	69	-.46	-.62	.02	.57	.84	-.12	.12	.72
c.	1.56	34	-.49	-.66	.15	.34	.63	-.08	.08	.55
d.	1.03	42	-.48	-.64	.09	.58	.80	-.05	.05	.75

WASHINGTON WEST, DC

	PHI 1	PHI 2	A	B
MEAN	.74	-.16	.16	.58
S.D.	.12	.07	.07	.06

STATION	BROOKDALE
DIST(km)	3.53
YEARS	14
ELEV(m)	79.25
LAT(deg)	38.95
LONG(deg)	77.1



LAT.	38.88
LONG.	77.00
C.I.	10
YEAR	909

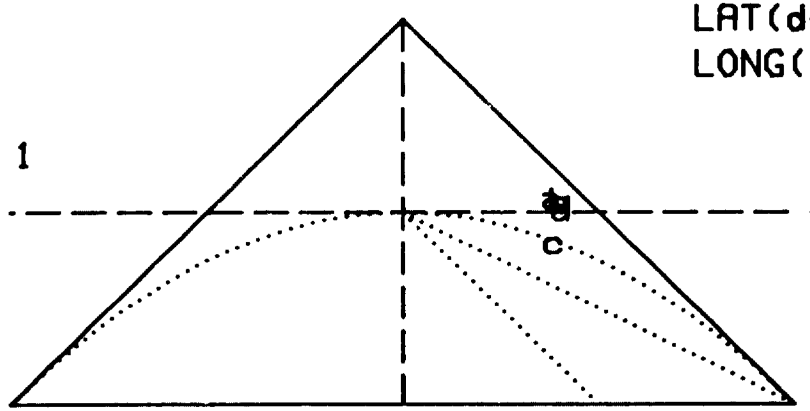
	MEAN	S.D.
TEMP.	X	0.00
PREC.	117.65	2.04

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.02	60	-.46	-.63	.09	.29	.59	-.11	.11	.48
b.	.19	44	-.47	-.64	-.13	.42	.71	-.11	.11	.60
c.	.83	50	-.51	-.67	.19	.47	.79	-.17	.17	.62
d.	.87	79	-.47	-.64	.12	.50	.86	-.26	.26	.60

MOUNT MITCHELL, NC

	PHI 1	PHI 2	A	B
MEAN	.78	.00	-.00	.79
S.D.	.03	.10	.10	.11

STATION	CELO
DIST(km)	11.89
YEARS	10
ELEV(m)	822.96
LAT(deg)	35.83
LONG(deg)	82.18



LAT.	35.75
LONG.	82.25
C.I.	40
YEAR	1010

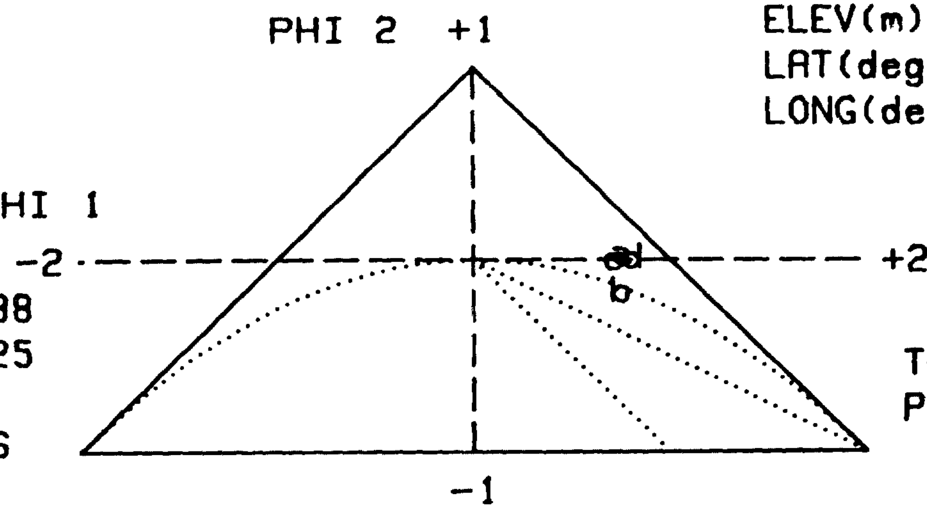
	MEAN	S.D.
TEMP.	10.89	7.35
PREC.	143.66	2.22

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.10	23	-.52	-.69	.23	.67	.75	.08	-.08	.83
b.	.98	40	-.49	-.66	.17	.73	.80	.06	-.06	.86
c.	1.08	46	-.49	-.69	.11	.46	.77	-.15	.15	.62
d.	.35	50	-.52	-.69	.20	.68	.81	.02	-.02	.83

STRASBURG, VA

	PHI 1	PHI 2	A	B
MEAN	.76	-.02	.02	.74
S.D.	.04	.09	.09	.10

STATION	RIVERTON
DIST(km)	9.76
YEARS	29
ELEV(m)	167.64
LAT(deg)	38.93
LONG(deg)	78.2



LAT.	38.88
LONG.	78.25
C.I.	20
YEAR	1966

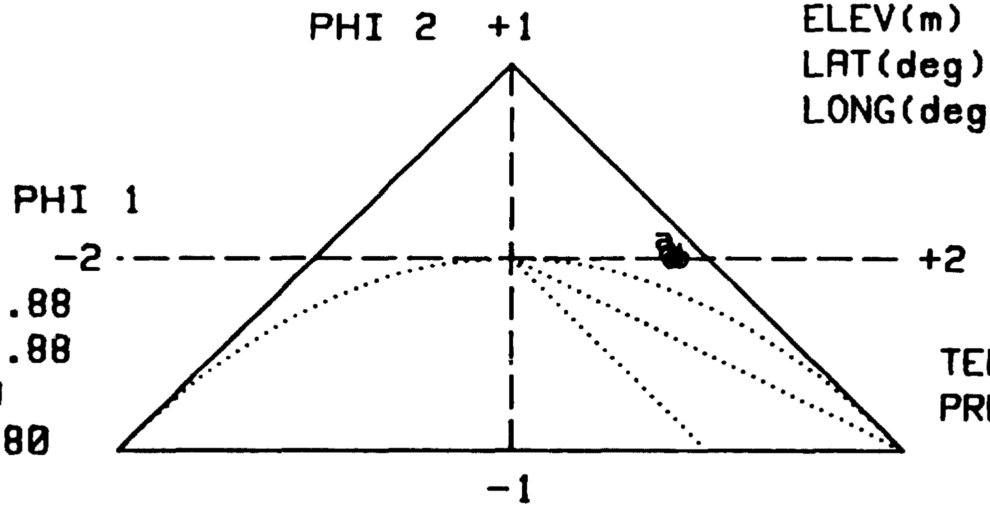
	MEAN	S.D.
TEMP.	X	0.00
PREC.	89.97	1.51

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.07	39	-.51	-.67	.16	.61	.75	.04	-.04	.79
b.	.09	63	-.51	-.67	.14	.44	.75	-.15	.15	.60
c.	.41	48	-.50	-.68	.22	.53	.72	.01	-.01	.73
d.	.33	32	-.48	-.64	.13	.69	.81	.02	-.02	.83

SHERANDO, VA

	PHI 1	PHI 2	A	B
MEAN	.82	.05	-.05	.86
S.D.	.04	.04	.04	.02

STATION	TYE RIVER
DIST(km)	33.74
YEARS	22
ELEV(m)	216.41
LAT(deg)	37.63
LONG(deg)	78.93



LAT.	37.88
LONG.	78.88
C.I.	40
YEAR	1980

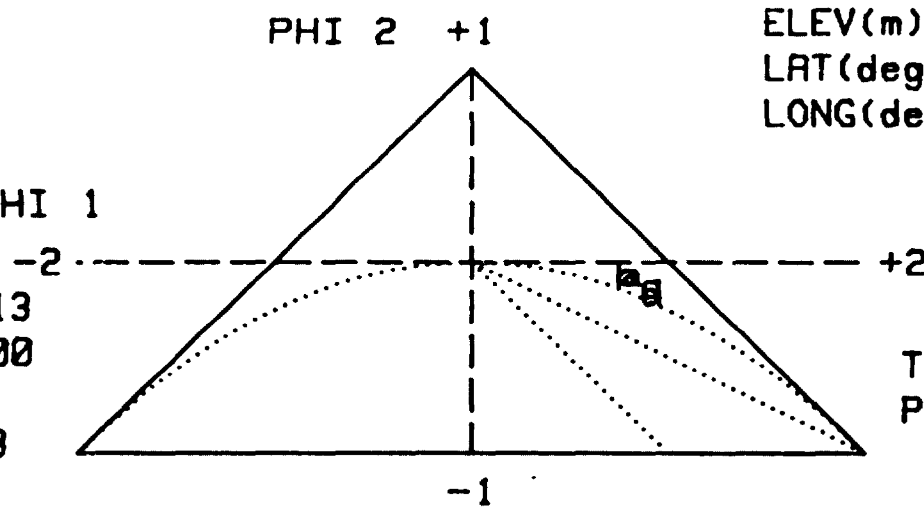
	MEAN	S.D.
TEMP.	X	0.00
PREC.	108.81	1.92

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.73	43	-.51	-.67	.16	.76	.77	.11	-.11	.88
b.	.72	54	-.49	-.63	.06	.77	.86	.02	-.02	.88
c.	1.30	46	-.49	-.65	.16	.72	.81	.05	-.05	.85
d.	.40	76	-.49	-.66	.13	.70	.83	.01	-.01	.84

NORRIS, TN

	PHI 1	PHI 2	A	B
MEAN	.86	-.10	.10	.76
S.D.	.07	.05	.05	.03

STATION	KNOXVILLE
DIST(km)	29.42
YEARS	21
ELEV(m)	296.88
LAT(deg)	35.95
LONG(deg)	83.92



LAT.	36.13
LONG.	84.00
C.I.	20
YEAR	1973

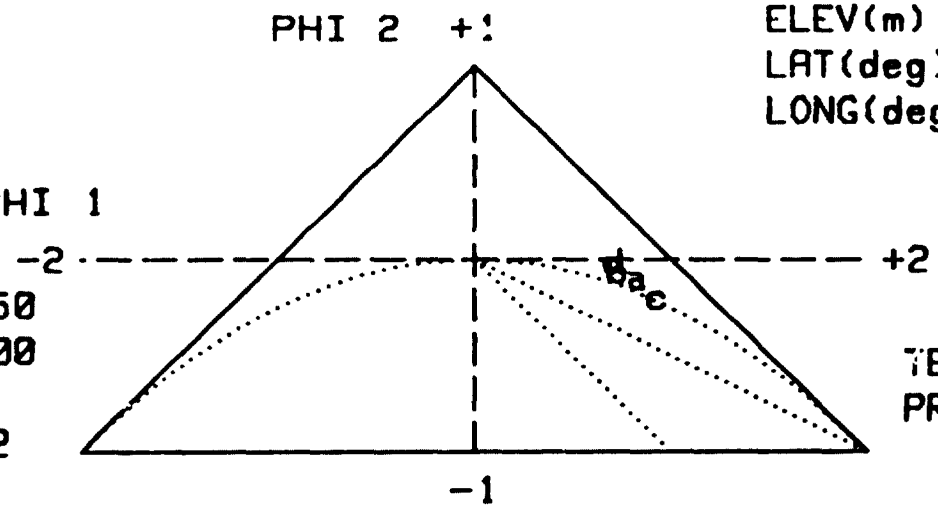
	MEAN	S.D.
TEMP.	15.28	8.18
PREC.	116.92	2.18

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.08	34	-.51	-.65	.14	.59	.81	-.06	.06	.75
b.	.79	51	-.56	-.73	.32	.56	.79	-.06	.06	.73
c.	.25	58	-.46	-.60	-.01	.68	.92	-.12	.12	.80
d.	.08	55	-.49	-.65	.10	.64	.92	-.16	.16	.76

ALEXANDRIA, PA

	PHI 1	PHI 2	A	B
MEAN	.80	-.09	.09	.71
S.D.	.10	.08	.08	.03

STATION	HUNTINGTON
DIST(km)	7.95
YEARS	72
ELEV(m)	206.65
LAT(deg)	40.5
LONG(deg)	78.02



LAT. 40.50
LONG. 78.00
C.I. 20
YEAR 1972

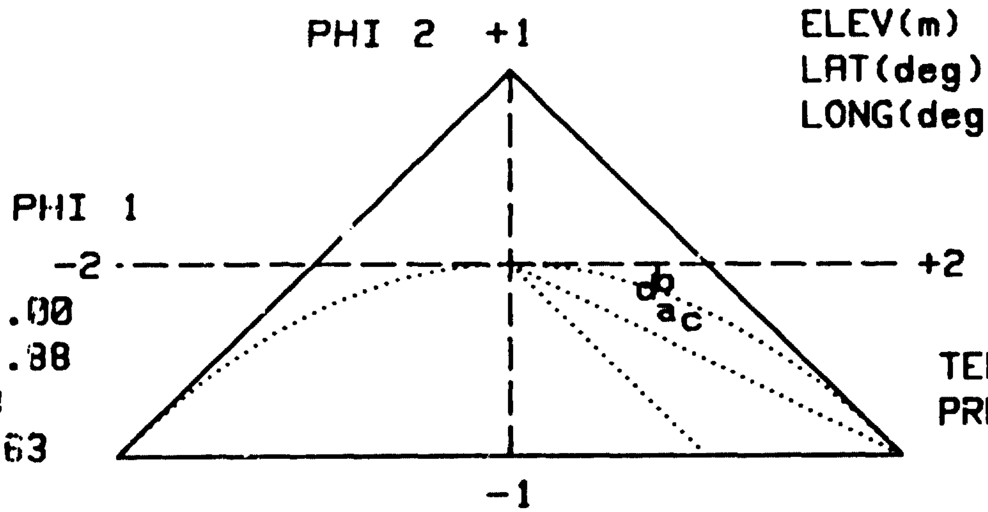
	MEAN	S.D.
TEMP.	10.44	9.13
PREC.	102.29	1.46

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.87	53	-.50	-.67	.18	.57	.82	-.09	.09	.73
b.	.61	24	-.51	-.66	.18	.48	.73	-.06	.06	.67
c.	.60	42	-.47	-.65	.14	.62	.93	-.19	.19	.74
d.	.10	70	-.42	-.57	-.06	.49	.71	-.01	.01	.70

SAUGERTIES, NY

	PHI 1	PHI 2	A	B
MEAN	.80	-.18	.18	.63
S.D.	.10	.09	.09	.07

STATION	SHOKAN-BROWN STA.
DIST(km)	26.28
YEARS	20
ELEV(m)	163.07
LAT(deg)	41.95
LONG(deg)	74.22



LAT.	42.00
LONG.	73.88
C.I.	10
YEAR	1963

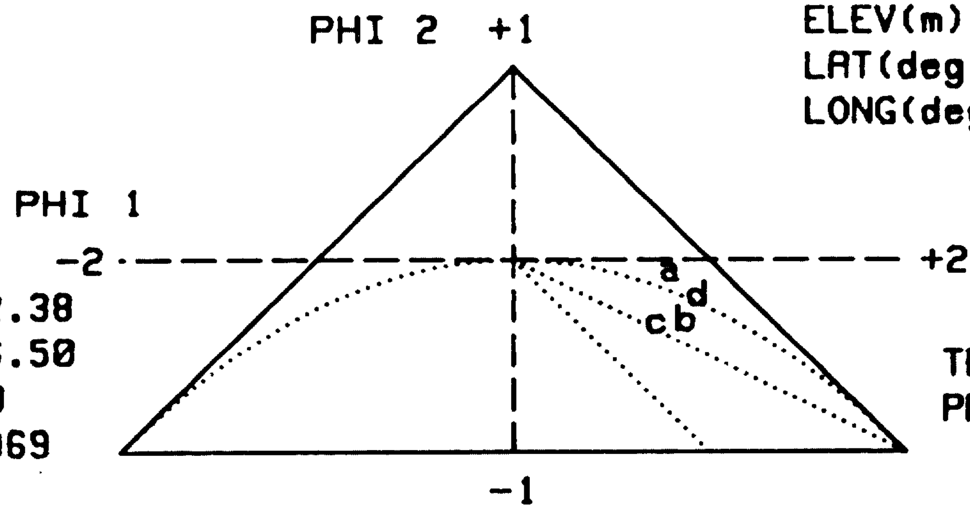
	MEAN	S.D.
TEMP.	X	0.00
PREC.	123.82	1.28

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.14	43	-.44	-.60	.01	.44	.79	-.23	.23	.56
b.	.07	41	-.47	-.63	.08	.54	.79	-.08	.08	.71
c.	1.50	83	-.47	-.63	.04	.56	.93	-.28	.28	.65
d.	.47	46	-.48	-.68	.09	.40	.70	-.12	.12	.58

ITHACA WEST, NY

	PHI 1	PHI 2	A	B
MEAN	.84	-.21	.21	.63
S.D.	.09	.13	.13	.16

STATION	ITHACA
DIST(km)	8
YEARS	20
ELEV(m)	289.56
LAT(deg)	42.45
LONG(deg)	76.47



LAT.	42.38
LONG.	76.50
C.I.	10
YEAR	1969

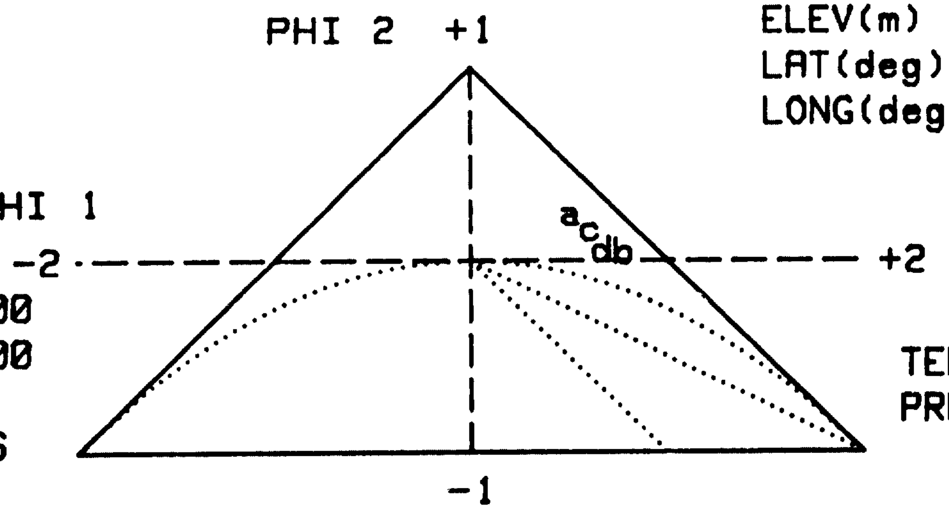
	MEAN	S.D.
TEMP.	8.33	9.58
PREC.	91.08	1.58

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	2.77	61	-.41	-.58	0.00	.58	.79	-.04	.04	.75
b.	2.78	35	-.51	-.69	.24	.51	.88	-.30	.30	.58
c.	1.54	63	-.55	-.71	.23	.38	.73	-.31	.31	.42
d.	3.53	38	-.50	-.69	.26	.66	.94	-.17	.17	.77

FAYETTEVILLE, WV

	PHI 1	PHI 2	A	B
MEAN	.64	.13	-.13	.77
S.D.	.12	.10	.10	.04

STATION	OAK HILL
DIST(km)	13.11
YEARS	19
ELEV(m)	607.16
LAT(deg)	37.97
LONG(deg)	81.15



LAT. 38.00
LONG. 81.00
C.I. 40
YEAR 1976

	MEAN	S.D.
TEMP.	10.94	8.38
PREC.	113.28	1.88

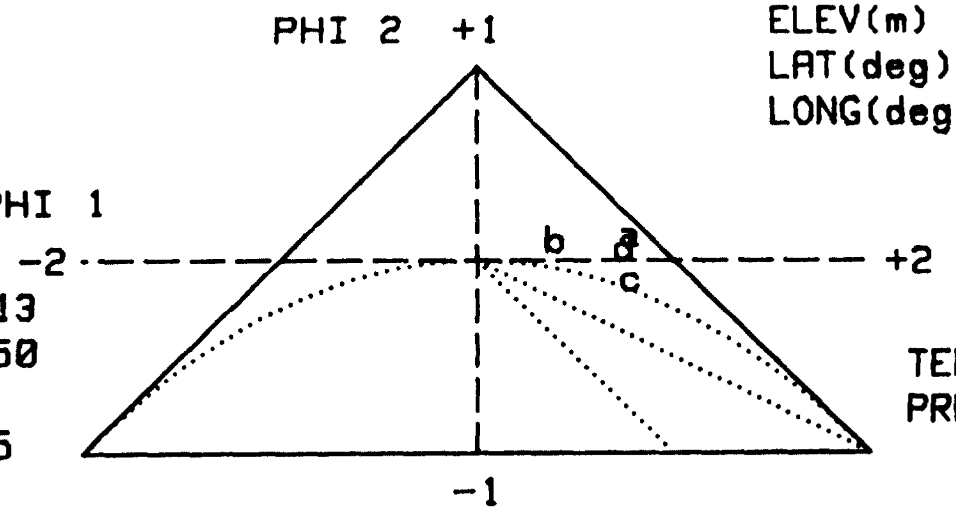
C-3

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.31	74	-.47	-.64	.15	.48	.50	.25	-.25	.75
b.	0.00	75	-.47	-.65	.17	.67	.78	.05	-.05	.83
c.	.21	63	-.53	-.72	.32	.55	.61	.17	-.17	.78
d.	.25	82	-.46	-.64	.12	.51	.67	.06	-.06	.73

WHITWELL, TN

	PHI 1	PHI 2	A	B
MEAN	.68	.06	-.06	.73
S.D.	.18	.10	.10	.17

STATION	MONTEAGLE
DIST(km)	25.59
YEARS	22
ELEV(m)	584.61
LAT(deg)	35.25
LONG(deg)	85.83



LAT. 35.13
LONG. 85.50
C.I. 20
YEAR 1965

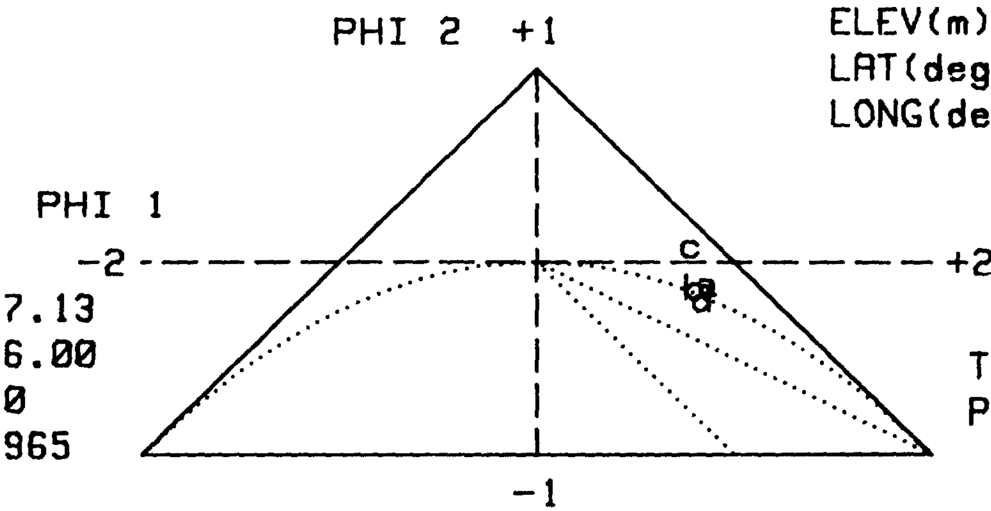
	MEAN	S.D.
TEMP.	13.89	7.86
PREC.	152.68	3.21

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.06	72	-.45	-.64	.15	.81	.77	.14	-.14	.91
b.	.45	55	-.48	-.64	.08	.21	.40	.11	-.11	.51
c.	1.50	58	-.47	-.66	.19	.52	.78	-.09	.09	.69
d.	.40	41	-.50	-.66	.14	.65	.75	.07	-.07	.82

MAMMOTH CAVE, KY

	PHI 1	PHI 2	A	B
MEAN	.82	-.09	.09	.74
S.D.	.04	.12	.12	.10

STATION	MUNFORDVILLE
DIST(km)	18.15
YEARS	30
ELEV(m)	190.2
LAT(deg)	37.27
LONG(deg)	85.88



LAT.	37.13
LONG.	86.00
C.I.	20
YEAR	1965

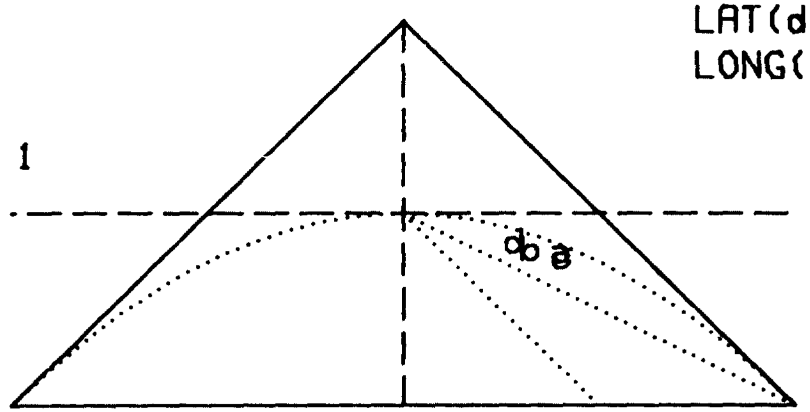
	MEAN	S.D.
TEMP.	X	0.00
PREC.	122.81	1.91

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.07	57	-.56	-.71	.24	.61	.86	-.11	.11	.75
b.	.26	44	-.49	-.67	.22	.51	.80	-.13	.13	.67
c.	1.10	36	-.50	-.65	.11	.74	.78	.09	-.09	.87
d.	.01	53	-.52	-.69	.23	.52	.84	-.19	.19	.65

HILLSBORO, KY

	PHI 1	PHI 2	A	B
MEAN	.71	-.18	.18	.53
S.D.	.12	.03	.03	.09

STATION	FLEMINGSBURG
DIST(km)	12.74
YEARS	35
ELEV(m)	265.18
LAT(deg)	38.42
LONG(deg)	83.72



LAT.	38.25
LONG.	83.63
C.I.	20
YEAR	1951

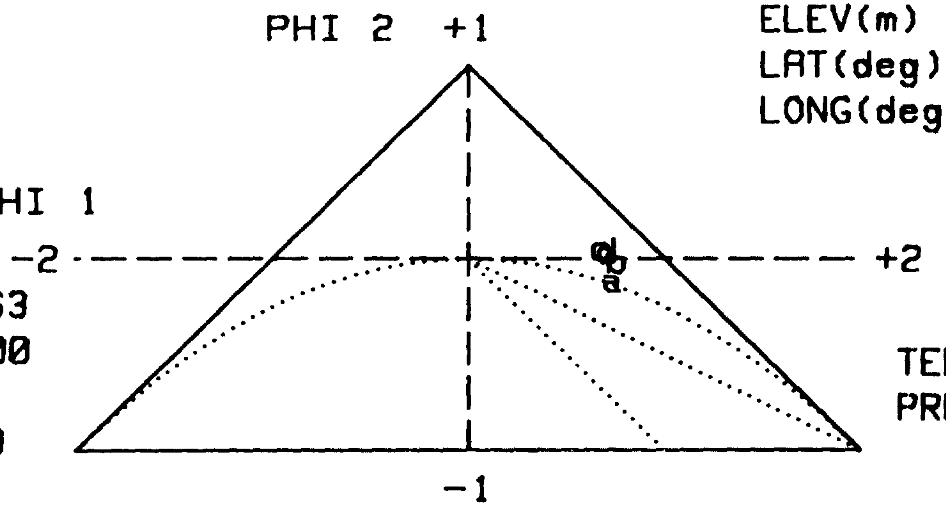
	MEAN	S.D.
TEMP.	X	0.00
PREC.	115.80	1.71

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.02	58	-.57	-.73	.28	.47	.80	-.19	.19	.61
b.	.40	73	-.53	-.71	.27	.33	.65	-.18	.18	.47
c.	.16	49	-.52	-.68	.19	.47	.81	-.22	.22	.59
d.	.35	72	-.57	-.75	.38	.26	.57	-.14	.14	.43

ROVER, TN

	PHI 1	PHI 2	A	B
MEAN	.72	-.01	.01	.72
S.D.	.03	.08	.08	.06

STATION	MCMINNVILLE
DIST(km)	23.75
YEARS	79
ELEV(m)	274.32
LAT(deg)	35.68
LONG(deg)	85.8



LAT.	35.63
LONG.	86.00
C.I.	10
YEAR	1949

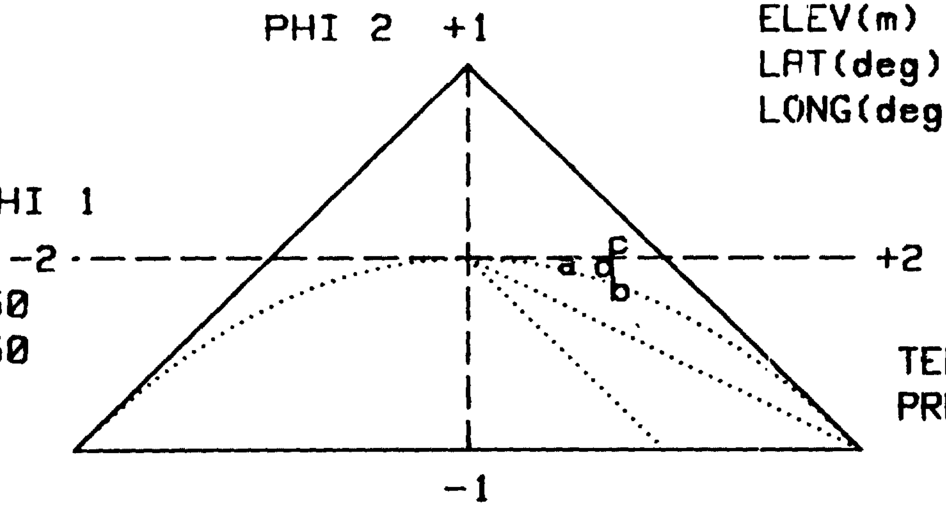
	MEAN	S.D.
TEMP.	15.44	7.81
PREC.	132.08	2.11

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.13	40	-.55	-.73	.35	.44	.73	-.11	.11	.62
b.	.76	41	-.52	-.67	.15	.57	.76	-.01	.01	.75
c.	.44	39	-.50	-.67	.18	.53	.68	.06	-.06	.74
d.	.01	55	-.50	-.65	.13	.55	.71	.04	-.04	.75

AYER, MA

	PHI 1	PHI 2	A	B
MEAN	.69	-.03	.03	.66
S.D.	.13	.10	.10	.16

STATION	GROTON
DIST(km)	4.5
YEARS	72
ELEV(m)	103.63
LAT(deg)	42.6
LONG(deg)	71.58



LAT.	42.50
LONG.	71.50
C.I.	10
YEAR	404

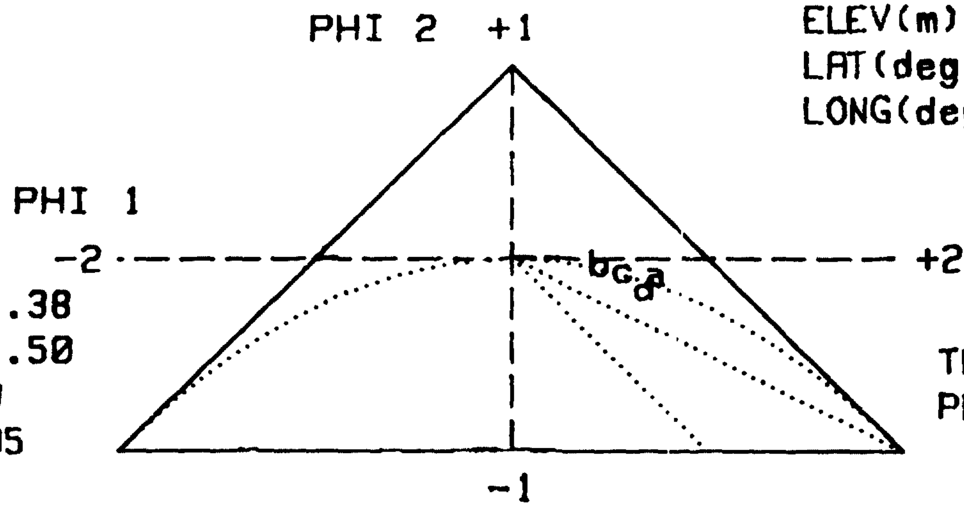
	MEAN	S.D.
TEMP.	X	0.00
PREC.	109.07	.38

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.11	69	-.50	-.65	.07	.24	.50	-.02	.02	.48
b.	.25	67	-.51	-.69	.24	.47	.78	-.16	.16	.62
c.	.27	68	-.52	-.67	.15	.72	.77	.09	-.09	.86
d.	.05	45	-.49	-.65	.10	.46	.70	-.03	.03	.67

KINGSTON, RI

	PHI 1	PHI 2	A	B
MEAN	.61	-.07	.07	.54
S.D.	.12	.06	.06	.09

STATION	KINGSTON
DIST(km)	5.64
YEARS	72
ELEV(m)	30.48
LAT(deg)	41.48
LONG(deg)	71.53



LAT. 41.38
LONG. 71.50
C.I. 10
YEAR 505

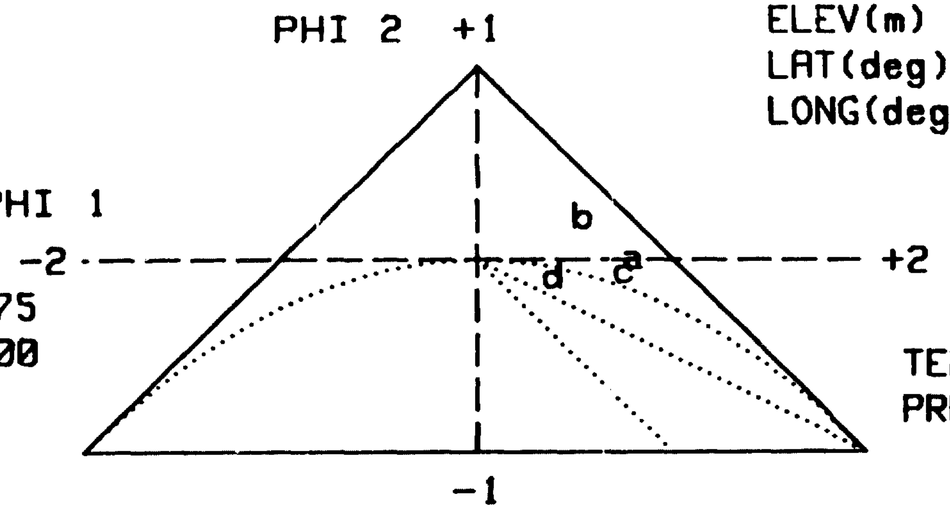
	MEAN	S.D.
TEMP.	9.06	8.63
PREC.	122.78	1.25

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.57	39	-.53	-.71	.32	.47	.73	-.07	.07	.66
b.	.08	68	-.49	-.67	.24	.19	.45	-.02	.02	.43
c.	.25	46	-.54	-.73	.35	.30	.57	-.05	.05	.52
d.	.60	84	-.51	-.68	.20	.36	.68	-.15	.15	.53

BRANDON, VT

	PHI 1	PHI 2	A	B
MEAN	.62	.03	-.03	.65
S.D.	.19	.14	.14	.23

STATION	CORNWALL
DIST(km)	19.66
YEARS	65
ELEV(m)	103.63
LAT(deg)	43.95
LONG(deg)	73.22



LAT.	43.75
LONG.	73.00
C.I.	20
YEAR	606

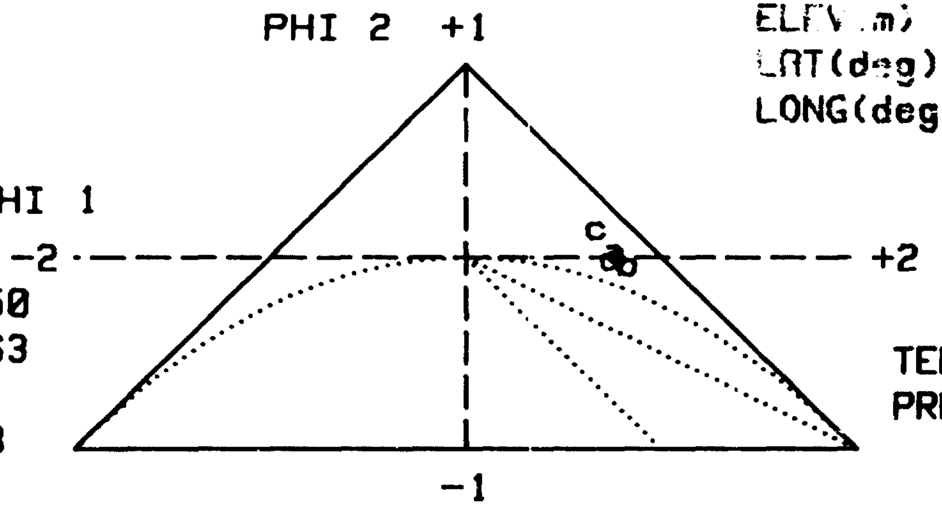
	MEAN	S.D.
TEMP.	7.67	10.52
PREC.	83.49	1.34

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.63	65	-.53	-.69	.18	.65	.79	.02	-.02	.81
b.	1.78	56	-.47	-.66	.20	.52	.54	.23	-.23	.77
c.	.10	29	-.50	-.68	.21	.51	.75	-.05	.05	.70
d.	1.18	30	-.46	-.61	.03	.14	.39	-.08	.08	.31

IRONTON, MO

	PHI 1	PHI 2	A	B
MEAN	.75	.04	-.04	.79
S.D.	.07	.08	.08	.04

STATION	ARCADIA
DIST(km)	6.67
YEARS	82
ELEV(m)	282.24
LAT(deg)	37.58
LONG(deg)	90.62



LAT. 37.50
LONG. 90.63
C.I. 20
YEAR 1968

	MEAN	S.D.
TEMP.	12.72	9.08
PREC.	113.67	1.77

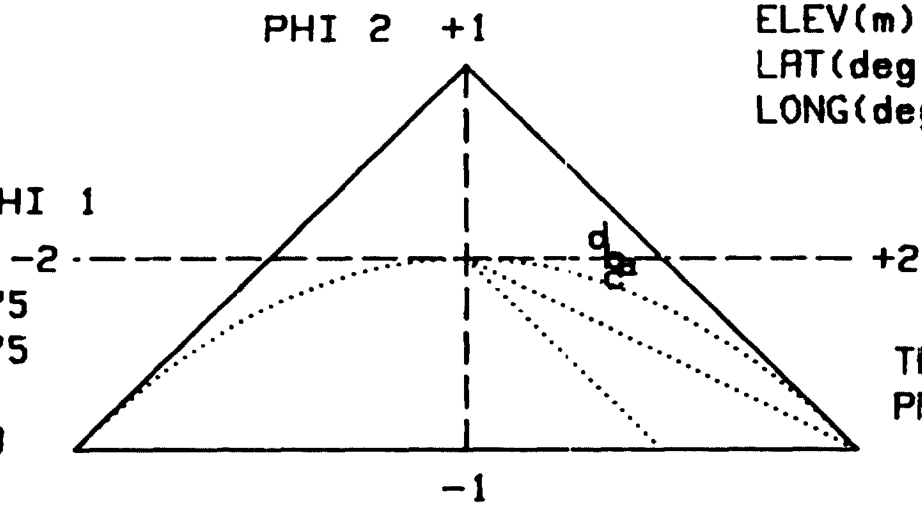
	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.14	59	-.51	-.66	.15	.63	.76	.04	-.04	.80
b.	.56	47	-.54	-.70	.24	.65	.83	-.03	.03	.80
c.	.13	48	-.50	-.67	.18	.65	.67	.16	-.16	.83
d.	.26	59	-.45	-.64	.16	.55	.74	0.00	0.00	.74

ST PAUL, AK

	PHI 1	PHI 2	A	B
MEAN	.76	.01	-.01	.76
S.D.	.06	.09	.09	.06

STATION	BUFFALO TOWER
DIST(km)	28.84
YEARS	15
ELEV(m)	785.77
LAT(deg)	35.87
LONG(deg)	93.5

PHI 1



LAT.	35.75
LONG.	93.75
C.I.	40
YEAR	1973

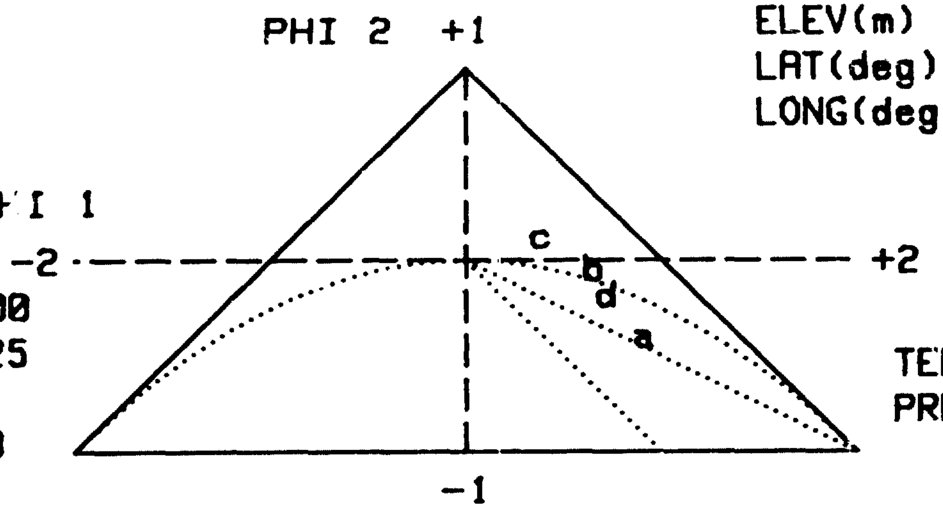
	MEAN	S.D.
TEMP.	X	0.00
PREC.	139.09	3.14

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.05	36	-.48	-.64	.08	.65	.82	-.02	.02	.80
b.	.41	48	-.53	-.70	.26	.59	.76	.01	-.01	.77
c.	.79	80	-.54	-.71	.25	.49	.76	-.09	.09	.67
d.	.08	61	-.54	-.72	.29	.60	.68	.12	-.12	.80

FIDELITY, MO

	PHI 1	PHI 2	A	B
MEAN	.67	-.12	.12	.55
S.D.	.21	.2[illegible]	.22	.05

STATION	JOPLIN
DIST(km)	20.27
YEARS	14
ELEV(m)	299.31
LAT(deg)	37.17
LONG(deg)	94.5



LAT.	3?.00
LONG.	94.25
C.I.	10
YEAR	1978

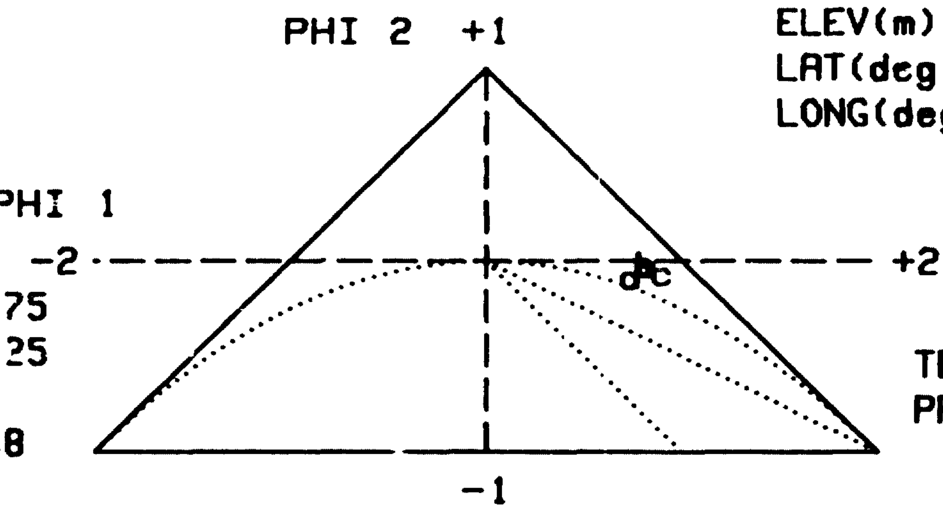
	MEAN	S.D.
TEMP.	14.39	9.42
PREC.	96.85	3.17

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.50	59	-.60	-.75	.36	.51	.90	-.39	.39	.51
b.	1.80	36	-.52	-.72	.33	.40	.65	-.04	.04	.62
c.	1.33	101	-.49	-.64	.08	.21	.38	.13	-.13	.52
d.	.17	32	-.51	-.67	.18	.40	.72	-.17	.17	.55

HORSESHOE MTN., AK

	PHI 1	PHI 2	A	B
MEAN	.82	-.04	.04	.77
S.D.	.07	.03	.03	.08

STATION	WALDRON
DIST(km)	21.7
YEARS	40
ELEV(m)	205.74
LAT(deg)	34.9
LONG(deg)	94.1



LAT. 34.75
LONG. 94.25
C.I. 20
YEAR 1958

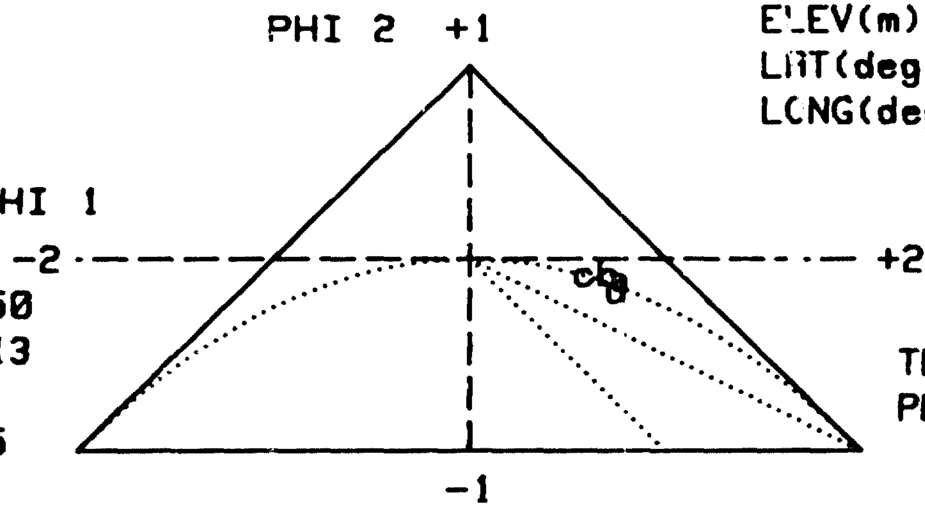
	MEAN	S.D.
TEMP.	16.39	12.46
PREC.	116.41	1.92

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.68	69	-.52	-.69	.26	.63	.80	-.01	.01	.79
b.	.56	82	-.49	-.64	.08	.65	.82	-.02	.02	.80
c.	1.16	68	-.59	-.72	.24	.72	.90	-.06	.06	.84
d.	.47	61	-.57	-.73	.29	.47	.74	-.08	.08	.66

MENA, AK

	PHI 1	PHI 2	A	B
MEAN	.70	-.10	.10	.60
S.D.	.08	.04	.04	.06

STATION	DANVILLE
DIST(km)	14.88
YEARS	44
ELEV(m)	112.78
LAT(deg)	35.05
LONG(deg)	93.4



LAT. 34.50
LONG. 94.13
C.I. 20
YEAR 1975

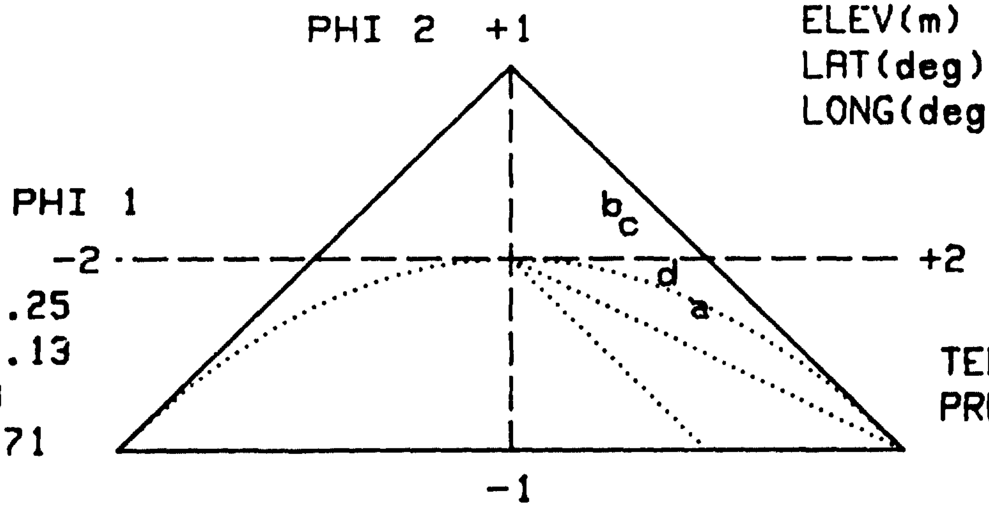
	MEAN	S.D.
TEMP.	X	0.00
PREC.	122.20	1.83

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	1.46	41	-.49	-.65	10	.48	.76	-.10	.10	.66
b.	1.53	45	-.49	-.66	.15	.44	.71	-.07	.07	.64
c.	.53	30	-.50	-.67	.13	.30	.59	-.07	.07	.51
d.	.65	25	-.47	-.64	.13	.43	.75	-.16	.16	.59

LAVACA, AK

	PHI 1	PHI 2	A	B
MEAN	.72	.04	-.04	.76
S.D.	.20	.24	.24	.05

STATION	FORT SMITH
DIST(km)	16.44
YEARS	15
ELEV(m)	139.6
LAT(deg)	35.33
LONG(deg)	94.37



LAT.	35.25
LONG.	94.13
C.I.	20
YEAR	1971

	MEAN	S.D.
TEMP.	16.39	8.87
PREC.	105.79	2.02

	ST. ERR.	CHI SQ.	DIF(1) LAG(1)	DIF(2) LAG(1)	DIF(2) LAG(2)	%VAR. EXP.	PHI 1	PHI 2	CREEP (A)	SLOPE WASH(B)
a.	.48	86	-.62	-.78	.43	.62	.96	-.24	.24	.71
b.	1.02	40	-.51	-.67	.18	.57	.52	.29	-.29	.81
c.	1.02	37	-.45	-.64	.14	.57	.60	.19	-.19	.79
d.	1.06	81	-.50	-.66	.17	.56	.80	-.07	.07	.73